NOAA FISHERIES
Southwest Fisheries Science Center

Ecosystem Science Review of the SWFSC
Summary of recommendations and responses
September 2016

Introduction

NOAA Fisheries conducts annual peer review science on a six-year cycle of each of its six Science Centers and headquarters' Office of Science and Technology. Each year a specific theme is emphasized. The 2016 NOAA Fisheries Science Program Reviews evaluated ecosystem science programs that inform the management, protection, and restoration of resilient and productive ecosystems. Ecosystem-related science programs are defined in the Ecosystem Science Program Review Terms of Reference as "those elucidating ecological, oceanographic, climate, and habitat-related processes as they are linked to living marine resource (LMR) species." In particular, this year's review assessed whether the Centers' science programs are adequately focused on priority ecosystem science information required to complete the National Marine Fisheries Service's mission.

The SWFSC's Ecosystem Science Program Review, held April 18-22, 2016, in the La Jolla Laboratory, covered the quality of our current ecosystem science activities and assessed our progress in transitioning to more holistic, ecosystem approaches to our science and research. We presented the ecosystem perspective of our science programs including those in: the California Current Large Marine Ecosystem, Antarctic Living Marine Resources, and North Pacific open ocean. The agenda and materials presented at the review are available from the SWFSC website[1].

The SWFSC ecosystem science review covered two large marine ecosystems, and multiple themes in the space of three days. The review included components of SWFSC ecosystem science for the Antarctic, the California Current Large Marine Ecosystem (CCLME) including elements of its managed species, pinnipeds (i.e., the CA sea lion program in collaboration with the Alaska Fisheries Science Center – the AFSC), and the Pacific highly migratory species (HMS) program. In each of these, aspects of management, ecosystem science and modeling were considered.

As such, the review panel members Drs. Robin Webb (Chair), Dan Costa, Éva Plagányi-Lloyd, Jeff Polovina, Eileen Hofmann and Doug DeMaster[2] were presented with a formidable task to provide an in-depth review covering topics in five topics (see Table 1). We thank each member of the panel for providing valuable feedback, direction and advice to the Center based on oral presentations, on-site discussions and on background material provided prior to the review. We appreciate and sincerely thank

[1] Results from past reviews of the Center's approaches to Data Management, Fish Stock Assessments, Protected Fish and Marine Mammal and Turtle Species are also available from the SWFSC site.

[2] Dr. Doug DeMaster's role on the panel was advisory on internal NOAA/NMFS processes to panel members. Dr. DeMaster is the Science and Research Director of the AFSC and recused himself from comments on the Centers' ecosystem programs since the CA Pinniped Program, housed partly in the AFSC, was part of this review. We thank Dr. DeMaster for taking on this role in the review process.

each member's thoughtful and constructive comments and advice. While the panelists' comments were focused largely along two lines, the Antarctic ecosystem and the CCLME, the panel also commented on ways in which the Center as a whole could consider integrating aspects of the programs.

Topic	Review Goal
1	*Management Context and Strategic Planning*
2	*Ecosystem Data*
3	*Ecosystem modeling and analysis*
4	*Incorporation into Management*
5	*Communication and Peer Review*

Table 1. Evaluation themes for the ecosystem science review

We also thank the supportive remarks we have excerpted from the Chair's report:

> *"The panel was impressed with the broad spectrum of marine ecosystem science research that the SWFSC is responsible for that includes a remarkable geographic range from the ocean surrounding Antarctic to the CCLME and a diverse suite of marine science topics that span fisheries, salmon stocks, marine mammals, migratory species and climate change considerations. Maintenance of the very long and rich research quality data time series contribute is an impressive effort and these data sets provide the foundation for conducting marine ecosystem science and for implementing ecosystem-based fisheries management in a changing climate, especially given the potential for significant future climate influences in Antarctica and CCLME and risk to living marine resources in response to rapid changes in environmental conditions.*
>
> *There is clearly also a lot of mutual respect amongst staff, and a positive working environment. … There is a good mix of empirical, analytical and modeling approaches which provides a firm basis for providing scientific outputs that are grounded with real data."*

The Chair's report is provided in Appendix 1 and the individual reviewer comments are listed in Appendix 2 of this document. The Chair's report provides a high-level summary, rather than a consensus, of the panelists' recommendations. The reviewers addressed all five review topics and their evaluations yielded six main themes of specific recommendations (described below and summarized in Table 2) that the Center should consider addressing in the coming years. While these themes are presented as separate items, they are in many ways fundamentally linked. In the end, our approach will be to weave our steps, for both our Antarctic efforts and those in the CCLME, into a more consolidated Center-wide effort. Acronyms are listed in Table 3.

The key summary points are provided here as they reflect comments from all reviewers and the Chair on areas where the SWFSC community should consider taking actions

resulting from this review. We provide our responses based on the Chair's summary and panel members' reviews.

Response to Summary Recommendations

1. Integration of SWFSC Ecosystem Science (internally and externally)

Representative Panel and Chair's recommendations:

- The SWFSC Ecosystem Science Program should continue to strive to improve integration between different research areas, and develop an integrated overview of the structure and function of large marine ecosystems that draws on the existing wealth of data and scientific understanding within the center.

- The SWFSC should be more systematic in how it sets ecosystem science priorities and evaluates how well these priorities are met.

- The research being carried out in the California Current Ecosystem is quite impressive and has many examples of EBM and EBFM. However, while the program is impressive and producing some amazing data it has yet to reach its full potential. The most significant issues are collaboration between groups and the development of some larger big-picture hypothesis that could help to better integrate research across the various divisions.

- There is clear evidence of ecosystem science threads being embedded in much of the science that is being done, but a less clear picture emerged of an overall strategy to interweave these threads and ensure the sum is greater than the individual parts.

Action Item: We concur that better integration of the ecosystem science activities is needed and is something we will actively pursue. We will integrate our ecosystem science in a four-pronged approach:

i. Internally, the Center Management Team (CMT) will develop Terms of Reference (ToR) for a Center-wide uniform ecosystem science strategy. The ToR will be implemented by a Center Ecosystem Science Committee (CESC) that will identify areas of scientific overlap between our Center's activities in the CCLME and in the Antarctic.

ii. To facilitate the work of the CESC we will also establish a CCLME team to develop an overarching strategy for ecosystem research within the CCLME.

iii. In partnership with the NWFSC, the WCRO, the PFMC, the PSRG and other science and management bodies we will implement the WRAP (Western Regional Action Plan) whereby we will integrate ecosystem and climate objectives for the U.S. West Coast oceanic and watershed domains.

iv. More broadly, we will actively engage with external partners in the Antarctic (e.g., through or with the Palmer LTER, SOOS, SCAR, etc.) and in the CCLME with

OAR (ESRL, GFDL, PMEL), NOS, USFWS, States, etc., in defining common areas of research. These links will be bi-directional, linking SWFSC long time-series and expertise developed over the past 20+ years with larger scale (climate) signal work from partner organizations.

2. Synthesis of existing efforts

Comments on needed syntheses of data and integrated studies were offered specific to the Antarctic and the CCLME. We consider these separately below although there is clear overlap in the approaches to achieve synthesis.

Action Item: We will consider possible comparative studies across systems for which we are responsible, as well as more broadly across other systems globally, e.g., other upwelling and high latitude systems. There is an opportunity to take advantage of the long time series to do comparative analyses for the same species and parameters across ecosystems or basins, as well as between species. There appears to be a need for greater focus on the complete ecosystem structure and function to complement the present strong bottom-up emphasis. An ecosystem modeling team (see Section 3 below) will be important to this work

Antarctic – Panel and Chair's recommendations

- The AERD (and AMLR) should undertake syntheses and comparative studies of its long-term data sets and publish these as a book (e.g., *AGU Antarctic Research Series*) and/or special issue(s) of a peer-reviewed journal (e.g., *Deep-Sea Research II*). The SWFSC should provide resources and personnel time to develop dedicated publications for the AMLR data.

- The impact of these data sets would be significantly improved by a synthesis, comparisons with similar data sets from other areas of the Antarctic, and comparative studies to place them within a broader context. The need to link this synthesis to the program mandate for management is recognized.

- Time should be reserved to allow the scientists to increase publication of their results in the peer-reviewed literature. This should also include time for broader, more strategic reflection of the science conducted to date to consolidate these findings and strengthen linkages with other research groups and findings (e.g., climate information, other predator monitoring programs).

- A break in fieldwork is envisioned during every third year. The "off year" could be an opportunity to conduct retrospective analysis and a series of publications to both review sampling design and communication more broadly with the scientific community.

- AERD should consider strategic approaches for providing input to CCAMLR so that CCAMLR-related papers can transition into publications for peer-reviewed scientific publications.

Action Item: We concur that synthesis and publication of our Antarctic work are important. Synthesis will allow for better refinement of future fieldwork, including hypothesis-driven research (see Section 4 below) and further consideration of the rapid climate-change effects observed and expected to continue around the Western Antarctic Peninsula (WAP). We will undertake new synthesis efforts.

CCLME – Panel and Chair's recommendations

- While climate change was a theme for some components of the CCLME it was missing in some presentations, even though the data were available to relate the observations to climate driven processes.

- Publication of synthesis and integrative studies should be given a high priority and supported. A systematic synthesis of individual data sets and across-data set synthesis is needed (e.g., pinniped data collected by the SWFSC and AFSC in the CCLME), as is placing these data within a broader context through comparative studies. The CCLME would benefit from comparative studies with other upwelling systems, especially in terms of developing scenarios for responses to natural and anthropogenic climate change.

- Individual components of the CCLME program provide useful and interesting data and results. However, it is not obvious that these components are part of an overall larger conceptual view of the California Current System. Developing a larger view will help with setting priorities for observational programs, developing approaches for system integration, and providing advice for management.

Action Item: We concur that continued synthesis and publication of our CCLME work with special attention to comparative approaches is important. The SWFSC has unique data sets (on upwelling systems including lower-, mid- and upper-trophic levels components) as well as the needed in-house scientific expertise that will be brought to bear to achieve these studies.

3. Ecosystem Modeling and Management Strategy Evaluations (MSEs)

There was consistent and clear advice from the Panel on the immediate need to establish ecosystem and oceanographic (linked to climate) modeling capabilities in the Center. Panel members indicated that not having such modeling capabilities is a deficiency shared by the Antarctic and the CCLME programs. Similarly, the panel members noted that quantitative incorporation of the ecosystem and climate-modeling results could be achieved through MSEs. Again, these recommendations apply to both Antarctic and CCLME elements.

A general recommendation illustrating several Panel members' concern was "The SWFSC should recognize ecosystem modeling as a priority and develop approaches for providing a critical mass of individuals with this expertise and stable long term funding. The robustness to climate change also needs to be explored. Given that climate change is likely a critical underlying driver of predator population dynamics, it is important to test the performance of a decision rule taking into account both short-term and long-term variability."

Antarctic – Panel and Chair's recommendations

- Modeling expertise that can help with examining and identifying critical data sets should be developed within AERD. The AERD should work with the SWFSC Director to develop a plan for hiring an ecosystem modeler with a focus on the Southern Ocean.

- AERD should work with the SWFSC Director to ensure that a MSE for the Antarctic system is a priority for the new hire. In the short term, modeling expertise can be obtained via collaborations and through hires of postdoctoral researchers.

- The Antarctic is highly variable and hence regular updates through a feedback management approach may well be needed, but it seems likely that similar performance could be achieved with 3-yearly updates for example (or a simpler rule). Management strategy evaluation should be used to pre-test the performance of alternative decision rules that include updating at different frequencies, as well as exploring the possibility of data not being available in some years. The robustness to climate change also needs to be explored.

- Conducting management strategy evaluations to compare the benefits and performance of [the presented FBM] approach to other precautionary approaches would be an important step going forward. … Is the krill feedback model and associated sampling robust to changing climate that may alter krill growth/mortality, spatial distribution, etc.?

CCLME – Panel and Chair's recommendations

- One of my key recommendations is to create at least one more ecosystem modeler position with responsibility for synthesizing the Center's research and to provide a more holistic overview and understanding of the CCLME, in a way that links the physical environment, full foodweb from plankton to top predators, as well as human and socio-economic considerations.

- The CCLME should move towards mechanistically based modeling approaches. Understanding climate and its effects on the CCLME ecosystem, fisheries, and management would be facilitated by the availability of a MSE, which would also provide a framework for integrating and synthesizing across the CCLME program.

- Incorporation of ongoing modeling activities and additional hires with ecosystem modeling expertise are critical to the success of a CCLME MSE. A version of the Atlantis model (a MSE) seems to have been implemented for the California Current System, but results and recommendations based on this model were not obvious to the review committee. Better integration of this MSE into CCLME science is needed.

- The Center has a strong research program assessing the role of bottom-up (upwelling) in the ecosystem but research on food web dynamics and uses of

ecosystem models were not well highlighted in the review talks. It is important that this component of ecosystem research receives considerable attention and takes advantage of ecosystem models. A full time ecosystem modeler position would be an important contribution to this effort.

- My main recommendation is thus to create an ecosystem modeler/s position to focus on developing one or more coupled physical-biological models of the system, preferably at the regional scale (regional downscaling should be a priority), and also incorporating higher trophic level predators.

Action Item: We concur that establishing a strong ecosystem modeling capability is a priority as is building MSE capabilities. Efforts are underway by the SWFSC to hire an individual who will lead the development and establishment of an MSE framework in the Center. The SWFSC is also planning an additional hire with ecosystem modeling expertise. These capabilities will be established deliberately and planned so that the Center as a whole benefits from the enhanced modeling and MSE capabilities. We realize that two individuals cannot alone undertake development of ecosystem and oceanographic models and MSEs. In the short-term (until stable permanent additional funding can be secured) we will consider attracting postdoctoral scientists and partnering with other NOAA Line Offices, academia and international programs to build the needed critical mass and teams.

4. Hypothesis-driven research and maintenance of fieldwork in support of the SWFSC's time-series

Panel members were laudatory about the value of the time series collected in the Antarctic and CCLME and recognized the significant and sustained effort on the part of the SWFSC staff. It was also noted that some of the data sets are approaching time scales that can be used to address climate issues. However, panel members also commented that while attention has been paid to maintenance of effectively "legacy" time-series, equal attention appears *not* to have been given to hypotheses driving the continued collection of the time series. They also noted that a reduction in field effort (in part driven by funding constraints) offers an opportunity for analysis of the field programs and associated experimental design.

Antarctic – Panel and Chair's recommendations

- Whilst recognizing the tremendous value of existing and ongoing data collection, resources and staff are clearly overstretched and it might be worth revisiting what the optimal field data collection program looks like. Unless strong justification can be provided for undertaking surveys annually, the frequency of these could potentially be reduced to say two out of every three years. One way to assess what level of sampling frequency is necessary would be to simulation test the impact of different data availability on scientific assessments of the status and productivity of the ecosystem.

- If time or resources were made available, it would be informative to collate climate data and projections for the region and perform analyses to determine the extent to which trends in available data might be explained by climate

signals. There is great potential for analysis of the existing time series within the context of climate change. Such an effort could benefit from inclusion of LTER data and personnel and individuals from the ERD.

- Hypothesis-driven research may be implicit in individual research projects, but hypotheses that integrate across AERD programs are not apparent. Collaborative field efforts with other nations that can potentially mitigate gaps in time series data sets (more probable for land-based data sets) should be pursued.

- The AERD program needs to work out a way of maintaining a summer field program for both the predator observations and the ship-based surveys. These are the only predator prey and oceanographic data that are collected in the Southern Ocean that are appropriately matched in time and space.

Action Item: The collection of time-series data in the Antarctic is driven by the intent to detect the ecosystem impacts of fishing over the background of environmental variability and change. However, we concur that the time series should be revisited to more explicitly consider other hypotheses that can be addressed by future observations. These include climate effects, as well as measurements that enable comparative analyses across systems or species. We will convene a planning meeting to identify hypothesis-driven research that can be executed in the next 3-5 years.

CCLME – Panel and Chair's recommendations

- CCLME research programs are focused around providing management advice and seem to lack a hypothesis-driven basis. Integration of CCLME research within and across divisions would be facilitated by across-program hypotheses. Hypothesis-driven research will also help with comparative studies, such as with other upwelling systems that will place the CCLME results into a larger context.

- Many of the CCLME time series appear to be legacy data sets, i.e., data continue to be collected to serve the time series rather than for a specific scientific objective. Few of these time series have undergone synthesis and publications based on the time series are limited.

- The pinniped data (specifically California sea lions - CSL) is a spectacular data set and time series. This is the only example of a time series where the diet, demography and to a limited extent the movement patterns of a marine mammal population that has recovered from earlier exploitation have been combined. The CSL demographic data set is the first example where the mandate of the Marine Mammal Protection Act of 1972 has been achieved. This is the example of a population where the parameters set out in the MMPA (OSP, OSY, K) have been able to be quantified. Further, the CSL is the only sea lion out of 6 species that has been increasing and recovered. From a management perspective such data can provide critical insights to understand why these other populations are in decline.

Action Item: We concur, as we did for the Antarctic time series, that the CCLME time series strategy should include more explicitly stated hypotheses that the observations

can answer. These include climate effects, as well measurements that enable comparative analyses across systems or species. Collaboration with partners will be built into revised research plans.

5. Management

Antarctic – Panel and Chair's recommendations

- The feedback management approach now under development by AERD does not explicitly account for climate and environmental variability and seems overly complex. Feedback management should consider a less complex approach that incorporates climate and makes use of proxies that are readily obtainable.

- AERD's [feedback management] FBM concept is scientifically sound, innovative and potentially a world-leading example in implementing a tactical ecosystem-based management approach. However, the complexity of the concept and logistical challenges in ensuring and maintaining its implementation in an ongoing fashion point to the need to consider whether there are simpler approaches that might work almost as well in terms of meeting management goals related to acceptable risks to predators.

- I was impressed with the level of sophistication. [AERD has] significantly advanced the conceptual framework and potential implementation of EBFM for krill. The approaches developed here can be applied to other systems. Further, if any EBFM program has a possibility of implementation it will be within CCAMLR.

- The [FBM] model/approach is innovative, it uses multiple data sets, it's adaptive, responding to changing conditions, incorporates ecosystem indices, and produces tactical advice. It represents the leading edge of an ecosystem approach to fisheries management. However, it is a complicated approach requiring considerable field and analytical work to maintain and potentially producing highly temporally dynamic quotas. It might be worth considering a more phased in approach such as using the ecosystem indices as separate indicators in conjunction with a krill assessment model with a decision rule to adjust the krill harvest based on moving average of the ecosystem indicators.

- The commitment by AERD personnel to the development of a Ross Sea MPA is commendable. However, the Ross Sea is not a focus for the AMLR program and efforts with the Ross Sea MPA divert AERD personnel and resources from more directly relevant activities. The AERD should consolidate its efforts to focus on the South Shetland Islands region of the Western Antarctic Peninsula (WAP). From a scientific perspective an ongoing focus of research efforts in the WAP region that capitalizes on the long history of existing research, will firmly establish the AERD as world leaders in advancing ecosystem research and implementation in the Antarctic region.

- AERD has taken on a leadership role in the development of MPAs in the Southern Ocean that will have global implications. Precedents agreed upon for MPAs in CCAMLR will help develop MPAs in other regions of the world, so it is

important for the USA to play a leadership role here and AERD is the appropriate agency to do this. Finally, [the] AERD team has the expertise to address this issue and AERD is therefore in an excellent position to lead this effort. However, it might be worth considering whether additional resources can be provided to AERD to accomplish this rather new and increasingly time consuming task.

Action Item: It appears that the panelists had mixed opinions about how the AERD should, in the future, support the development of a feedback management strategy for the krill fishery and the establishment of MPAs. Two action items are planned, both of which link to other action items identified elsewhere in this response. First, the AERD will, over the next two years, work to develop a simpler FBM approach. When that approach has been developed, we plan to use management strategy evaluations to compare the new simpler approach to the approach that has already been developed and was presented to the panel (see also the action items under Section 3). Second, in 2017, the leadership of SWFSC will meet with relevant leadership from the Department of State, National Science Foundation, Marine Mammal Commission, environmental NGOs, and other U.S. stakeholders with interests in Antarctica to discuss future requirements for scientific advice and how the research needed to meet these requirements might best be provided by the activities of AERD and NSF-funded researchers. Such discussions link to the actions items under Sections 2 and 6 because, without new resources, the AERD must find an appropriate balance of the time and resources needed to synthesize its historical research, provide relevant and timely scientific advice on issues relevant to decision making within CCAMLR, advance feedback management and climate-related research, and collect data in the field.

CCLME – observations

- The West coast Regional Action Plan (WRAP) under development is an excellent and much needed umbrella to integrate all the research and co-ordinate the provision of climate-related information to support decision-making.

- Both the Region and Council expressed a need to incorporate climate information in their actions. The Center has two major initiatives to address climate impacts. One is the Western Regional Action Plan (WRAP) and the other is the species Climate Vulnerability Analysis (CVA). A draft of the WRAP has been completed and is undergoing external review. This is a joint effort with the NWFSC and follows the approach presented in the NOAA Fisheries Climate Science Strategy. The CVA is being conducted through various working groups and is ongoing.

Action Item: We thank the panel for its observations and endorsement of our actions with respect to CCLME climate strategies.

6. Other recommendations and comments by the Panel and the Chair

- Historically the AMLR program had a strong and viable partnership with the NSF Office of Polar Programs (now Division of Polar Programs) that provided logistical and financial support that was critical to maintaining some of the AMLR time series (e.g., penguins) and field camps. This partnership has eroded in

recent years possibly because of the change in the program manager for the Antarctic Organisms and Ecosystems program from a permanent to rotator position. The current structure at NSF Polar Programs does not provide the continuity that existed previously. Re-establishing a partnership with NSF Polar Programs might provide support for some of the AMLR field activities that will be lost with the upcoming reduction in field resources.

Action Item: We will be placing a high-level AERD employee at NSF's Office of Polar Programs in an effort to reenergize the relationship and re-institutionalize the ties between the two programs. In addition, we will endeavor to participate in forthcoming, annual meetings of the Palmer LTER.

- [The AERD] is a small high achieving research group that are clearly very dedicated and enthusiastic. However they are clearly overstretched in terms of available resources, given also the complexity of logistical arrangements to undertake Antarctic fieldwork, long time commitments necessary for fieldwork and CCAMLR meetings, inordinate amounts of time need[ed] in international negotiations and consultation, as well as analyzing data, performing analyses and writing technical reports. This has clearly left little time for professional development such as attending scientific conferences (particularly on broader topics), peer-reviewed publications, communicating and interacting with colleagues, as well as time to step back and reflect on the science as a whole. The latter is important to capitalize on the wealth of information and science conducted to date, as well as ensure that there are opportunities for a broader strategic overview of the science and facilitation of linkages with other areas.

- The Dept. of State is getting good information from AERD that is being used in the CCAMLR process. More resources would provide more data that would be used and allow an expansion of US involvement in CCAMLR. This would allow the USA to take a larger leadership role. Given the limited resources currently available they have to make strategic decisions on what things to do and not do. There is room for more capacity and more resources would allow them to take on a larger role.

- The Antarctic is projected to experience significant impacts from climate change, warming, loss of sea ice, ocean acidification, etc. Yet there was little discussion of how the ecosystem may change spatially, structurally, and functionally by the 2050's in response to climate change that might provide a strategic context for research and management.

Action Item: As noted in Section 5, the leadership of SWFSC will meet with relevant leadership from the Department of State, National Science Foundation, and other stakeholders to discuss future requirements for scientific advice and how the research needed to meet these requirements might best be provided by the activities of AERD and NSF-funded researchers. Such discussions will be scheduled for 2017 and aim to help the AERD find an appropriate balance of the time and resources needed to synthesize its historical research, provide relevant and timely scientific advice on issues relevant to decision making within CCAMLR (including feedback management and marine protected areas), advance climate-related research, and collect data in the field.

- CCLME should develop a social media strategy that will engage stakeholders and the general public. The annual State of the California Current System report should be transitioned to a web-based system with the option for real-time updates.

Action Item: We will explore options to expand outreach and engagement activities, as well as how the California Current System report might become more web-based.

- SWFSC should formalize succession planning of the lab's ecosystem science research leadership positions. Challenges in maintaining some research areas suggest there is a need for strategic succession planning.

Action Item: The Center leadership team is taking on conducting more thorough succession planning exercises to identify where we are vulnerable so we can address gaps.

- SWFSC should explore dedicated mentoring and other ways to increase the diversity of the scientific staff, particularly at the more senior levels. As with ecosystems and the importance of diversity in community resiliency, it was noted that a scientific monoculture could result in a lack of diversity of ideas that in turn can suppress innovation.

Action Item: We are looking at ways to diversify where we advertise senior positions as well as using new tools made available recently in the areas of phased retirement whereby senior positions formally mentor 'new blood'.

Table 2 Action items in response to the six themes from the SWFSC Ecosystem Science Review

Theme	Action Item	Schedule
1. Integration of SWFSC Ecosystem Science (internally and externally)		
a. SWFSC	CMT will develop ToRs for climate strategy	CMT retreat planned for winter 2017
	Form Center Ecosystem Science Committee (CESC) to identify areas of overlap	Spring 2017 following climate strategy ToRs
b. CCLME	Along with partners (NWFSC, WCRO, PFMC, etc.) implement the WRAP	Winter 2017 following approval of WRAP by NMFS HQ
c. Area of Influence	Engage with external partners in both Antarctic and CCLME to define climate-scale common efforts	Throughout 2017 and beyond. AERD staff will increase engagement with SCAR, SOOS, ICED, LTER, etc.
2. Synthesis of existing efforts		
a. Antarctic	Undertake a new synthesis of the available data* to date	Finish in Spring/Fall 2018 with target publications in peer-reviewed journals or book
	Use the synthesis to inform future planning	Spring/Fall 2018
b. CCLME	Similarly undertake a synthesis of available data including the CA pinniped research groups of the AFSC and SWFSC	Finish in Spring 2018 with target publications in peer-reviewed journals or book
3. Ecosystem Modeling and Management Strategy Evaluations (MSEs)		
a. SWFSC	Establish a strong ecosystem modeling capability	First modeler hire will be a shared hire with OAR/ESRL, Spring 2017
	Use the modeling capability to support MSE capabilities	First MSE scientist will start in Fall 2016
	Continue to seek funds to support postdoctoral scientists	Ongoing through many programs
	Continue to partner with other Science Centers, WCRO, NOAA line offices, academia and agencies	Ongoing (e.g., through implementation of the CCIEA, WRAP, etc.)
4. Hypothesis- driven research and maintenance of fieldwork in support of the SWFSC's time-series		
a. Antarctic	Antarctic science and time-series field work must be hypothesis driven. Hold planning meeting to identify hypothesis-driven research to be executed during 2017-2020	Winter 2016 or Spring 2017
b. CCLME	Similarly, revisit CCLME time series in light of hypothesis driven science (including CA pinniped program)	Convene a CCLME workshop in Spring 2017
5. Management		
a. Antarctic	Develop a "simpler" FBM strategy and compare to existing strategy and test with an MSE*	Fall 2018
	Review the needs for scientific advice within CCAMLR role (with State Department and, NSF, Marine Mammal Commission, environmental NGOs, and other stakeholders)	Spring 2017
b. CCLME	On the right path with WRAP development	Complete revisions, release final version in Fall 2016

6. Other recommendations and comments by the Panel		
a. SWFSC	Develop succession planning strategy	
	Develop mentoring and diversity strategies for senior positions	
b. Antarctic	Review and strengthen NSF ties	Spring 2017
c. CCLME	Expand outreach and engagement activities	
	Continue transition of State of California Current reports to a more dynamic web-based delivery	

*It is not clear that 2a and 5a can be completed simultaneously. The relative commitment to each of these action items will be contingent on the results of consultations with DOS, NSF, etc. as per the second element of Action Item 5a.

Table 3: Acronyms

AERD	Antarctic Ecosystem Research Division	NGO	Non-Governmental Organizations
AFSC	Alaska Fisheries Science Center	NOAA	National Oceanic and Atmospheric Administration
AMLR	(US) Antarctic Marine Living Resources Program	NOS	National Ocean Survey
CCLME	California Current Living Marine Resources	NSF	National Science Foundation
CESC	Center Ecosystem Science Committee	NWFSC	Northwest Fisheries Science Center
CMT	Center Management Team	OAR	Ocean and Atmospheric Research
CSL	California sea lions	OSP	Optimum Sustainable Population
CVA	Climate Vulnerability Analysis	OSY	Optimum Sustainable Yield
DOS	Department of State	K	Carrying Capacity
EBFM	Ecosystem Based Fishery Management	PFMC	Pacific Fishery Management Council
EBM	Ecosystem Based Management	PMEL	Pacific Marine Environmental Laboratory
ERD	Environmental Research Division	PSRG	Pacific Scientific Review Group
ESRL	Earth Systems Research Laboratories	S&T	Office of Science and Technology
FBM	Feedback Management	SCAR	Scientific Committee for Antarctic Research
GFDL	Geophysical Fluid Dynamics Laboratory	SOOS	Southern Ocean Observing System
HMS	Highly Migratory Species	SWFSC	Southwest Fisheries Science Center
ICED	Integrating Climate and Ecosystem Dynamics	ToR	Terms of Reference
LMR	Living Marine Resources	USFW	U.S. Fish & Wildlife
LTER	Long Term Ecological Research	WAP	Western Antarctic Peninsula
MMPA	Marine Mammal Protection Act	WCRO	West Coast Regional Office
MPA	Marine Protected Area	WRAP	Western Regional Action Plan
MSE	Management Strategy Evaluation		

Appendix 1

Chair's Summary of Program Review of Ecosystem Science Southwest Fisheries Science Center La Jolla, California April 2016

REVIEW PANEL:

Dr. Robert Webb	(Chair and other NOAA LO) NOAA Earth System Research Laboratory Physical Sciences Division
Dr. Dan Costa	(external) University of California Santa Cruz
Dr. Éva Plagányi-Lloyd	(external) Commonwealth Scientific and Industrial Research Organization (CSIRO)
Dr. Jeff Polovina	(NMFS Scientist) NOAA Pacific Islands Fishery Science Center
Dr. Eileen Hofmann	(external) Old Dominion University
Dr. Doug DeMaster	(NMFS Science Center Director) NOAA Alaska Fisheries Science Center

Outline of the Report

Scope and Context of Review
Objective
Overarching Questions for Reviewers
Background
High Level Challenges and Recommendations
Panel Members' Major Recurrent Observations and Recommendations

Scope and Context of Review

Periodic reviews of ecosystem-related science programs are used to ensure that the National Marine Fisheries Service (NMFS) achieves its mission of as a steward of living marine resources using science-based conservation and management approaches, and the protection and restoration of healthy ecosystems. The reviews of science programs at the NMFS SWFSC were conducted to evaluate the quality, relevance, and performance of science and research and to strategically position the SWFSC in planning of future science and research.

Objective

The objective for the review was to evaluate the current scientific ecosystem-related science programs and to assess the extent that a current SWFSC science program is focused on the priority information needs required to support the NMFS mission. Reviewers are asked to provide advice on the direction and quality of the science programs that are conducted specifically in in a NMFS science center.

Overarching Questions for Reviewers

The reviewers were asked to provide advice on the direction of the SWFSC research programs conducted to meet fisheries management needs by considering a number of overarching questions:

1. Does the SWFSC have clear goals and objectives for an ecosystem-related science program? Is ecosystem-related science integrated with the other science activities across divisions within the center? Are the SWFSC ecosystem science and research activities appropriately prioritized and evaluated as part of an overall strategic plan?

2. Does the SWFSC ecosystem-related science programs focus on information to address the priority needs of the Regional Offices, other NOAA managers, Fishery Management Councils and Commissions, and other partners that require ecosystem- related information to achieve their mission?

3. Has the SWFSC appropriately established a Regional Action Plan to identify the major climate threats to the ecosystem, identify major vulnerabilities of living marine resources with respect to climate, address the core science needs to address impacts from a changing climate, and integrate this information into management advice, congruent with the NOAA Fisheries Climate Science Strategy?

4. What is the status of oceanographic, habitat, climate and ecological data required to fulfill ecosystem-related science needs? Has the SWFSC

developed strategies to obtain and manage such data?

5. Is the SWFSC appropriately analyzing and modeling ecosystem-level processes? Are cumulative and integrative ecosystem-level analyses being conducted? If not, is there a plan in place to initiate or contribute to the science needed to address cumulative impacts?

6. Is the SWFSC oceanographic, habitat, climate and ecological advice sufficiently included into living marine resource management advice? Are there suitable mechanisms to determine when such inclusion is warranted?

7. Are the SWFSC ecosystem-related science programs and products adequately peer-reviewed relative to their purpose and use? If not, has the Center/ST developed a strategy for peer-review?

8. Does the SWFSC appropriately communicate research results and resource needs to conduct ecosystem-related science to various managers, partners, stakeholders and the public?

Responses to these questions were framed as observations and then recommendations to address the issue.

Background

A panel of experts reviewed the NOAA NMFS Southwest Fisheries Science Center (SWFSC) Ecosystem Science Program over a three-day period in April 2016. The SWFSC Ecosystem Science was presented in two regionally focused areas and two methodological topics. The first part of the review focused on the Antarctic Ecosystem Research Division (AERD) that supports United States (U.S.) interests related to conservation and management of marine living resources by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), of which the U.S. is a Member. AERD also conducts research for long-term land- and sea-based data monitoring the status of the Antarctic ecosystem as mandated by the U.S. Antarctic Marine Living Resources (AMLR) Convention Act of 1984, thus the program of work undertaken and managed by the AERD is widely known as the U.S. AMLR Program. The second part of the review focused on research to provide the best available scientific information for stewardship and management of marine living resources in the California Current Large Marine Ecosystem (CCLME). The regional ecosystem science program forms the basis for moving to ecosystem-based approaches to management, and provides important inputs to the Pacific Fisheries Management Council, as well as assessments of the status of marine mammal and endangered species populations. The program includes substantial long-term data collection programs such as the California Cooperative Oceanic Fisheries Investigations (CalCOFI), fish surveys, and pinniped surveys. The third part of the review presented SWFSC Ecosystem Science program research to develop and apply marine ecosystem modeling to provide early warning and inform preparedness needed to support conservation and management of marine living resources policy and decision making for the CCLME. The fourth part of the review described SWFSC Ecosystem Science program approaches to work with international, national, state and local partners on collaborative research, dissemination and

application of science-based knowledge in support of NMFS mission responsibilities for the stewardship of the nation's ocean resources and their habitat. The summary report has integrated input on third and fourth parts of the review into the CCLME and CCE write up.

The structure of the review allowed sufficient time for asking questions after each presentation, and ample time for members of the public to ask questions. The dedication and enthusiasm of the SWFSC staff was appreciated by the reviewers, and the staff is to be congratulated on doing an outstanding job in delivering world-class science to inform decision making. A vast majority of the presentations were very well-presented with clear visual graphics and text. The panel was impressed with the broad spectrum of marine ecosystem science research that the SWFSC is responsible for that includes a remarkable geographic range from the ocean surrounding Antarctic to the California Current Large Marine Ecosystem and a diverse suite of marine science topics that span fisheries, salmon stocks, marine mammals, migratory species and climate change considerations. Maintenance of the very long and rich research quality data time series contribute is an impressive effort and these data sets provide the foundation for conducting marine ecosystem science and for implementing ecosystem-based fisheries management in a changing climate, especially given the potential for significant future climate influences in Antarctica and CCLME and risk to living marine resources in response to rapid changes in environmental conditions.

It is apparent that SWFSC leadership has done an excellent job in guiding the science agenda while working to overcome innumerable hurdles to maintain surveys and research effort, prioritizing needs and leveraging resources, despite the challenges faced. There is clearly also a lot of mutual respect amongst staff, and a positive working environment. Overall the Center has impressive facilities, and is putting these to good use. There is a good mix of empirical, analytical and modeling approaches which provides a firm basis for providing scientific outputs that are grounded with real data.

High Level Challenges and Recommendations

Science to support Ecosystem-Based Fisheries Management (EBFM) permeates much of the research and development conducted by the SWFSC Ecosystem Science Program. Nevertheless, it is not apparent that there is a clear picture of how all the research activities are integrated into a coherent research strategy in which the individual efforts are synergistically combined to ensure the sum is greater than the individual parts. The panel recognizes and applauds the ongoing efforts to better integrate what have been narrowly focused, and at times operating in isolation, research activities in the SWFSC Ecosystem Science Program; however, this transition period is an opportune time for the SWFSC to develop an all-encompassing, comprehensive ecosystem science strategy. Formulation of a coherent SWFSC ecosystem science strategy would provide the framework to link the Antarctic ecosystem research with other the regional ecosystem science activities to ensure that synergies and complementary research are better integrated and contribute to the collective learning and knowledge throughout the center. Development and implementation of an agreed upon SWFSC ecosystem science strategy would provide a structure to guide prioritization of research being undertaken, facilitate linkages and set up key hypotheses that require testing to ensure that these are well aligned with field data collection efforts. An outstanding

challenge for the SWFSC Ecosystem Science Program will be to decide if existing research should be consolidated and the best pathway forward in a funding environment of declining resources, particularly to support fieldwork. The SWFSC Ecosystem Science Program should continue to strive to improve integration between different research areas, and develop an integrated overview of the structure and internal functions of large marine ecosystems that draws on the existing wealth of data and scientific understanding within the center. The SWFSC Ecosystem Science Program would benefit from an enhanced ecosystem modeling capability to provide a structure to synthesize the independent ecosystem science activities and to develop relevant ecosystem models to support efforts in advancing ecosystem-based fisheries management approaches.

1. SWFSC should formalize succession planning of the lab's ecosystem science research leadership positions. Challenges in maintaining some research areas suggest there is a need for strategic succession planning.

2. SWFSC should explore dedicated mentoring and other ways to increase the diversity of the scientific staff, particularly at the more senior levels. As with ecosystems and the importance of diversity in community resiliency, it was noted that a scientific monoculture can result in a lack of diversity of ideas which in turn can suppress innovation.

3. SWFSC Ecosystem Research across the divisions would benefit from the presence of one or more full-time ecosystem modelers with responsibility for synthesizing research, providing a more holistic overview and understanding of the California Current and the Antarctic marine ecosystems, quantifying the role of physical drivers in influencing ecosystem dynamics, articulating the full food web from plankton to top predators, better utilizing and linking the plethora of rich data sets, and integrating human and socio-economic considerations.

4. SWFSC should provide greater emphasis on analysis and modeling of dynamical biogeochemical coupling in the California Current and in the Antarctic marine ecosystems through selective hires and/or strategic partnerships with external research organizations.

5. SWFSC should ensure that sufficient project review processes exist so that ecosystem science research activities are properly poised to advance the science and are well supported within the science. A part of this process should be a better articulation of testable hypotheses for the proposed science to be conducted at Antarctic and the CCLME that will help inform experimental design of the research projects.

6. SWFSC should be more systematic in how it sets ecosystem science priorities and evaluates how well these priorities are met.

7. SWFSC should develop a plan to make its ecosystem science research-based observational data more available with real time access.

8. While there was clear evidence of excellent high quality science, a greater effort is needed to capitalize on the wealth of data and understanding to provide a more integrated overview to support advancement of the ecosystem approach.

The SWFSC Ecosystem Science Program should actively encourage all lead scientists to devote time to consolidating existing research and synthesizing outputs and linkages across SWFSC.

9. The SWFSC Ecosystem Science Program needs to reassess the workplan priorities to free up time for staff for publishing in the peer-reviewed literature, broadening collaborations, attending scientific conferences and developing a hypothesis-based approach as a focus for ongoing data collection. The challenge is that across the Ecosystem Science Program, resources have shrunk and staff are overstretched with commitments to longstanding research objectives to maintain the same activities coming at the expense of time for personal scientific development.

10. The SWFSC Ecosystem Science Program should continue to work to ensure that it is well-positioned to lead regional EBFM implementation, recognizing that some aspects of EBFM are already in place but the actual implementation of EBFM remains rather slow to develop.

Review of the Antarctic Ecosystem Research Division (AERD)

AERD staff are to be commended for providing the unique and important scientific observations and knowledge needed for supporting Commission for the Conservation of Antarctic Living Marine Resources (CCAMLR) decision making as well as for building and maintaining a strong relationship with US and international policy makers. The AERD sits between stakeholders (e.g., fishing industry) and the CCAMLR Scientific Committee, the international commission that sets conservation measures that determine the use of marine living resources in the Antarctic. In this role, AERD is tasked with providing the best available scientific knowledge to inform policy, planning, and decision making related to management and use of Antarctic living marine resources. AERD provides this scientific knowledge drawing on research findings from the observation-based Antarctic Marine Living Resources (AMLR) program, the interpretation of observed changes in the context of fishing and climate impacts, and the prediction of potential ecosystem impacts of fishing and climate. AERD personnel lead, attend and participate in CCAMLR workings groups, the Scientific Committee, and contribute to the U.S. delegation that supports the work of the Commission. AERD research has advanced understanding of Antarctic ecosystem processes and the ecological effects of harvested species on dependent and related species. The latter has informed development of Ecosystem Based Fishery Management (EBFM) approaches for Antarctic marine living resources.

The value and critical role of the AMLR program in providing direct scientific input into the CCAMLR consultative process is clearly recognized by the U.S. Department of State. The AMLR program demonstrates the US commitment and scientific leadership within the Antarctic and greater international science communities. A survey of other national research programs confirmed the importance of the science conducted by the US AMLR program and the critical role this information continues to provide in the CCAMLR process.

At-sea and land-based data sets collected by the US AMLR program now extend for more than 25 and 30 years, respectively. The continuing decreases in resources to support personnel, logistics and science provide a threat and challenge to the continuation of these important data sets. The ship time available for the annual AMLR cruise has been reduced and the cruise shifted from summer to winter because of ship availability. Land-based predator surveys have been curtailed. The planned further reduction in field programs starting in 2017, with a 2-year on and 1-year off ship schedule provides an opportunity to assess and revise the AMLR sampling strategy and AERD resource allocations. This change is also an opportunity to conduct retrospective analyses, produce peer-reviewed publications and communicate more broadly with the scientific community. These activities will provide a framework to guide development of a more efficient field and ship survey data collection strategy that maintains the needed scientific and statistical rigor.

High Level Recommendations

The AERD supports NOAA and NMFS mission responsibilities as well as those of the U.S. Department of State and the nation in international negotiations, and maintaining this support requires change and transition in AERD activities. The world-class AMLR observation program provides long-term, continuous, high-quality observations of key marine ecosystem science in the Antarctic. However, AMLR needs to transition to a

research program that uses these observations in end-to-end analyses of Antarctic marine ecosystem structure and functioning. This requires hypothesis-driven data analyses and modeling that integrate biogeochemical and ecosystem processes to improve prediction and forecasting of species' co-dependency across trophic levels, from primary producers to top predators.

Key (Specific) Findings and Recommendations (as reviewer has comments on)

- **Theme 1 – Management Context and Strategic Planning**

Observations:
The development of Antarctic krill (*Euphausia superba*) and Antarctic toothfish (*Dissostichus mawsoni*) fisheries has identified management requirements that include the need for specific scientific data and advice on the development of marine protected areas (MPAs). As a result, AERD has prioritized development of an operational EBFM approach to regulate the krill harvest based upon monitoring the foraging behavior and demographics of key predators (e.g., seabirds and pinnipeds). AERD is also providing the science to support development of a process to establish MPAs in the Southern Ocean as a mechanism to preserve and protect components of Antarctic marine ecosystems.

The AERD is leading development of a Ross Sea MPA, a region where AMLR has negligible presence, and is taking a lesser role in the development of a MPA in the Antarctic Peninsula, where AMLR has significant presence. AERD is commended for supporting the Department of State with the scientific information and expertise needed to address issues related to the development of a Ross Sea MPA. However, AERD appears to be venturing into the policy arena (promoting and implementing US government positions), which seems to be moving beyond the expertise and role appropriate for a NMSF science center.

The continuing decline in AERD resources and support requires important and informed decisions about resource allocation and setting of priorities. The development of a five-year AERD strategic plan will help guide these decisions. Hypothesis-driven research may be implicit in individual AMLR research projects, but overarching hypotheses that integrate across AERD programs are not well articulated.

Recommendations:

1. AERD should work with the SWFSC leadership to develop a strategy for providing expertise in ecosystem modeling.
2. AERD should develop a strategic plan to guide its science program that is developed around coherent hypothesis-driven research and can be used to guide its research agenda, set priorities, and yield results readily compared across research efforts.
3. AERD should concentrate resources (staffing, operational, scientific focus) to build effectively on previous research efforts rather than expanding its focus.
4. AERD should initiate development and implementation of an operational research model that relies less on at-sea and land-based measurements and has a stronger focus on synthesis and modeling studies.
5. A less complex approach for feedback management assessments that incorporate climate variability and make use of proxies that are readily obtainable

should be considered to achieve consensus in implementing an ecosystem feedback protocol within the CCAMLR process.

6. AERD should develop an integrated ecosystem research strategy that links ongoing and planned observation programs with coupled models capable of projecting future states of Antarctic ecosystems.
7. AERD should work with the SWFSC leadership to obtain management strategy evaluation (MSE) expertise that can integrate the complex linkages and interactions between and among the components of the Antarctic ecosystem which affect changes in the distribution and biomass of the target species and their consequent effects on ecological, social and economic systems.
8. The AERD scientific research focus versus support of the Department of State policy should be examined to determine the appropriate balance. If promoting and implementing policies is an appropriate role for a NMFS science center, then NOAA should approach the Department of State with a request to provide support to the SWFSC for this policy-related service.

- **Theme 2 – Ecosystem Data**

Observations:
The oceanographic and land-based predator measurements collected by AMLR span several decades, providing an unequaled and critical temporal perspective that is approaching time scales that can be used to assess changes in climate and climate impacts. The extensive acoustic surveys (e.g., krill biomass) coupled with predator (e.g., penguins and seals) population demographic measurements provide important realizations of predator-prey dynamics. Data sets obtained from commercial krill fishing are important inputs for AERD assessments.

AMLR collects considerable oceanographic data during the annual cruise, but these data do not appear to be effectively used. AERD is making a commendable effort to make the AMLR data accessible through a web-based data portal, and is planning to add more data sets and improve access. However, the AMLR data are not particularly visible within the Southern Ocean community, possibly because of prior difficulties in obtaining these data through CCAMLR. As a result, the AMLR data have limited impact in scientific discussions, development of Southern Ocean programs, and informing Southern Ocean observing systems.

The dedication of the AERD staff to ensuring the success of the AMLR program is apparent. However, the staff has reached a “too much field time” limit. AERD personnel spend over 60 days in the field, and some more than 90 days, per year, which is not sustainable.

Because of reductions in resources (e.g., ship time) and logistics support the AMLR winter survey schedule was shortened. Plans are to implement a 2 out of 3 summer cruise schedule. The reduction in cruises and shortened land-based field seasons will significantly impact the time series that have been collected by AMLR over the last 30+ years, which are critical to CCMALR deliberations and decisions. A positive aspect is that the reduction in field activities may provide additional resources and time to facilitate data QA/QC and data availability while also reducing staff field time.

Recommendations:

1. The SWFSC and AERD should initiate a review to identify and prioritize field programs and data sets and adjust the investment of resources to ensure that critical data sets are maintained.
2. SWFSC and AERD should consider initiating a retrospective analysis of existing data time series to evaluate proposed future survey designs and sampling schemes to determine the ability of these proposed changes sampling strategies to resolve known variability in krill recruitment and predator foraging patterns and behavior and maintain efficient and statistically rigorous sampling.
3. Existing SWFSC in-house modeling expertise should be used to examine and identify critical AMLR data sets that should be sustained and/or developed.
4. AERD should explore the possibility of collaborative field efforts with other nations to mitigate potential future gaps in time series data sets.
5. AERD should undertake an evaluation to determine an optimal AMLR field data collection program with the constraint of a reduction in cruises to two out of every three years. Observing system simulation tests of the impact of different data availability on scientific assessments of the status and productivity of the ecosystem provide one approach for this evaluation.
6. Reductions in AMLR field time should be used for reflection, consolidation and professional development activities of the AERD research team, for programmatic support of data assessment, data availability, maintenance of a web-based data management system, and assessments of the role of climate impact in the observed variations and trends. The additional time should not be used to develop additional activities.
7. Given the wealth of experience and understanding, AERD and AMLR should consider becoming actively engaged in the Southern Ocean Observing System (SOOS) efforts to develop implementation plans for various regions of the Antarctica, with particular emphasis on the South Shetland Islands-Bransfield Strati region.
8. AERD should undertake syntheses and comparative studies of AMLR long-term data sets and publish these as a book or special issue(s) of a peer-reviewed journal.

- **Theme 3 – Ecosystem modeling and analysis**

Observations:

The AMLR field programs provide unprecedented time series of ecosystem processes in the northern part of the west Antarctic Peninsula. However, modeling and analysis of these data is only recently receiving significant attention. Considerable effort has been focused on the development of a krill feedback model, which adds spatial resolution to a statistical krill stock assessment model and incorporates ecosystem indices through penguin reproductive condition. The model is used to adaptively adjust the krill fishery harvest using feedback from predators and krill acoustic surveys. The modeling approach uses multiple data sets, is adaptive, responsive to changing conditions, incorporates ecosystem indices, and produces tactical advice. It represents the leading edge of an ecosystem approach to fisheries management. However, the modeling approach is complicated, requires considerable field and analytical work for implementation, and potentially produces temporally fluctuating dynamic quotas.

The analysis and diagnostic research supporting MPA development has involved assembling and mapping ecosystem data, outreach with stakeholders to identify objectives to be incorporated into the MPAs, and working with international partners to develop the details of the MPAs that will achieve CCAMLR consensus.

Within AERD there appears to a suboptimal research capacity for modeling and data analyses that result in an active and robust publication record. Furthermore, AMRL has not seemed to take effective advantage of the expertise of individuals within the SWFSC and other centers, such as AFSC. For example, the AERD top predator group could benefit from interactions with top predator researchers at the AFSC. In addition to a lack of MSE expertise, AERD seems to have a similar expertise gap in ecosystem modeling and analysis. This expertise is needed to maximize the impact of the AMRL data sets, to synthesize these data, and to develop diagnostic comparisons of observed variations and trends with similar data sets from other areas of the Antarctic.

The current AERD ecosystem-based modeling and analysis research capability would be significantly advanced by the availability of regional circulation, biogeochemical and food web models. Linking these regional models with fishery harvest, management, and economic models could provide inputs to make the feedback management process more robust. A suite of models that link across environment- ecosystems-socioeconomic-management will enhance the value of the AMLR data sets, provide a consistent framework for developing management advice, and allow testing the effects of a range of scenarios on harvesting and fishery management.

Recommendations:

1. AERD should consider a phased approach to development of the krill feedback model, such as using ecosystem indices as separate indicators in conjunction with a krill assessment model with a decision rule to adjust the krill harvest based on moving average of the ecosystem indicators.
2. The AERD should initiate a modeling and analysis research-based synthesis of the AMLR data sets and use this as a basis for comparative studies.
3. AERD should undertake statistical analyses, through comparison with historic data, to determine the loss in accuracy and precision that may occur if fishery vessels contribute significantly to krill data collection in some areas.
4. The AERD should initiate collaborations with groups within SWFSC, other NMFS centers, U.S. academic institutions, and international research centers (e.g., British Antarctic Survey IDEAL Center Chile) to develop and implement regional circulation, biogeochemical and food web models for the AMLR study region.
5. The AERD should work with the SWFSC leadership to ensure that the MSE hire has the time and resources to work with AERD personnel.
6. The AERD should work with the SWFSC leadership to develop a plan for hiring an ecosystem modeler to provide access to a spatial ecosystem modeling capability.

- **Theme 4 – Incorporation into Management**

Observations:

The AERD science is central to the development of ecosystem-based management for Antarctic marine resources and development of a feedback management approach is

part of its continuing contributions to this effort. AERD personnel provide important leadership within CCAMLR that guides the development of management strategies and provides the Department of State and US leadership at CCAMLR with the information needed to pursue US policy objectives. Advice provided by AERD has been central to achieving consensus on complex international negotiations about management of marine resources. The inputs from AERD directly support the needs of krill fisheries management and MPA development. These inputs are provided through participation by AERD personnel CCAMLR meetings and working groups and by submission of scientific reports detailing research findings.

The development of MPAs in the Southern Ocean is an important focus for the U.S. Department of State. AERD has played a central role in the development of MPAs in the Southern Ocean, especially the current effort to develop a MPA for the Ross Sea. These effort has required investment of considerable time and effort to develop, revise and negotiate the Ross Sea MPA plan. Much of this effort seems to have focused on dealing with political interests of various nations in order to develop a plan that can achieve consensus. The commitment by AERD personnel to the development of a Ross Sea MPA is commendable. However, the Ross Sea is not a focus for the AMLR program and efforts with the Ross Sea MPA divert AERD personnel and resources from more directly relevant activities and thus may not be the optimal use of AERD staff time. From an ecosystem science perspective, maintaining an ongoing focus of research efforts in the Antarctic Peninsula region that capitalizes on the long history of AMLR research will firmly establish the AERD as world leaders in advancing ecosystem research and implementation of fisheries management in the Antarctic.

Recommendations:

1. AERD personnel should continue to provide science inputs for Southern Ocean MPA planning and implementation but not at the level that impacts other mandates and priorities.
2. To achieve consensus in implementing an ecosystem feedback protocol, the AERD should consider adopting a less complex approach that is grounded in readily available data sets.
3. The AERD should strongly consider consolidating its research efforts to focus on the South Shetland Islands-Bransfield Strait region of the west Antarctic Peninsula.
4. The U.S. Department of State should be the lead for all geopolitical negotiations surrounding Southern Ocean MPAs. If promoting and implementing policies is an appropriate role for a NMFS science center, then NOAA should approach the Department of State with a request to provide support to the SWFSC for this policy-related service.

- **Theme 5 – Communication and Peer Review**

Observations:
AERD and AMLR are unique NOAA programs in that they maintain significant oceanographic and land-based survey components with challenging logistics, involve significant time and reporting demands from CCAMLR, and require inputs to development of ecosystem management approaches (e.g., krill harvest model and MPAs. The achievements of AERD in each of these activities are impressive and are

attributed to the dedication and enthusiasm of a small but high achieving research group.

The AMLR data sets and intellectual contributions by AERD personnel are critical to CCAMLR, and the Department of State seems satisfied with the current level and quality of communication of these. AERD research findings are communicated via CCAMLR working groups and papers as well as peer-reviewed journal publications. The working papers and background documents submitted to CCAMLR undergo a high level of peer review by working groups and committees. AERD staff invest considerable time in preparing and revising these papers; however, few of these transition to peer-reviewed publications in scientific journals. Publications in peer-reviewed journals show that AERD research in general and the AMLR program in particular is of high quality but the impact may be considered limited.

The AMLR program and AERD scientists are well respected within the CCAMLR community. Outside of the CCAMLR community, the national and international impact of AERD/AMLR is limited, even though it is a mature program. Time and funding constraints limit the ability of AERD personnel to participate in relevant meetings, conferences and workshops and to serve on national and international committees and working groups external to CCAMLR. Communication of ALMR research, especially of the field research results, to the general public is one example of where resources could be allocated to increase awareness of the key role and high quality of AMLR science.

Another ongoing communication challenge is that the methods for spatially disaggregating the overall krill catch (e.g., feedback rule) are complex and may be difficult for all stakeholders to understand.

Historically the AMLR program had a strong and viable partnership with the NSF Division of Polar Programs and its predecessors that provided logistical and financial support that was critical to maintaining some of the AMLR time series and field camps. This partnership has eroded in recent years possibly because of the change in the program manager for the Antarctic Organisms and Ecosystems program from a permanent to rotator position. The current structure at NSF Polar Programs does not provide the continuity that existed previously. A strong partnership with NSF Polar Programs that recognizes the importance of some of the AMLR field activities is needed so that support (e.g., field logistics) can possibly be provided for some data sets that are at risk of being discontinued with the proposed reduction in resources.

Recommendations:

1. AERD should allocate time and resources to encourage increased publication of scientific results in the peer-reviewed literature.
2. AERD should undertake syntheses and comparative studies of long-term AMLR data sets and publish these in a book or special issue(s) of a peer-reviewed journal in efforts to communicate program results to a wider community and result in a longer-term impact.
3. AERD should prioritize time and resources to facilitate elevating the visibility of the program through participation by staff in national and international activities outside of CCAMLR.

4. AERD should encourage and support staff to participate in wider range of scientific meetings, advisory committees, and activities.
5. AERD should consider strategic approaches for providing input to CCAMLR so that CCAMLR-related papers can transition into publications for peer-reviewed scientific publications.
6. AERD should consider developing simple summaries of the more complex scientific analyses being presented to CCAMLR working groups that could possibly promote greater understanding and better buy-in from other member nations.
7. SWFSC leadership should work with AERD to explore way to reinvigorate a strong and viable partnership with the NSF Division of Polar Programs recognizes the mutual benefit and importance of AMLR field activities.

Review of the California Current Large Marine Ecosystem (CCLME) and California Current Ecosystem (CCE)

The ongoing SWFSC ecosystem research in the California Current Large Marine Ecosystem (CCLME) and California Current Ecosystem (CCE) is impressive and extensive with major efforts focused in the California Cooperative Oceanic Fisheries Investigations (CalCOFI), fish (e.g., pelagic, demersal) surveys, and pinniped surveys. Many of these CCLME activities are mandated by legislative and regulatory constraints imposed by the Magnuson-Stevenson Act, Marine Mammal Protection Act, the Endangered Species Act, and many others. There are quite a number of impressive 30-plus year time series on California sea lions, ground fish, sardine and anchovies and salmon and the CalCOFI Program has collected some of the longest time series in the field of biological oceanography. A range of modeling approaches has been implemented for the California Current system and the SWFSC research programs have contributed to understanding of CCLME/CCE processes. The Western Regional Action Plan (WRAP), a joint product of the the SWFSC and NWFSC, reflects a coordinated effort across the region and presents a comprehensive approach to climate work in the region and a valuable tool for planning research planning. Ecosystem studies of the California Current System are distributed throughout four SWFSC divisions: Environmental Research Division, Fisheries Ecology Division, Fisheries Resources Division, Marine Mammal and Turtle Division. Overall the SWFSC staff are to be commended on building and maintaining a strong relationship in meeting fisheries management science-based information needs as evident by the strong support of and high regard for the California Current Ecosystem work by both the NMFS Regional Office and the Pacific Fisheries Management Council. The California Current Integrated Ecosystem Assessment provides a focus and plan for the SWFSC to move forward with the implementation of Ecosystem-based Fishery Management (EBFM) for the CCLME/CCE.

High Level Recommendations

While the SWFSC CCLME/CCE research program is remarkably successful, in a time of declining resources it is appropriate to undertake a critical review of investments in sampling programs and maintenance of time series, and to consider reallocation of resources to other efforts such as ecosystem modeling, synthesis and integration studies, MSE development, and use of autonomous measurement systems. For

example, the SWFSC maintains a number of long term survey and sampling programs that are becoming more challenging to maintain and thus the SWFSC would benefit from a review of all the cruises and data collection programs as part of an exercise to identify ways to develop a more integrated and efficient ecosystem survey program. A SWFSC-wide ecosystem strategy with division-specific objectives would help strengthen and coordinate ecosystem research. Many of the observation, analysis and modeling research efforts appear to operate in isolation and these efforts could be better integrated and synthesized. There is a noticeable absence of CCLME/CCE research on food web dynamics and use of ecosystem models that would benefit from the addition of full time marine ecosystem modeler position. In addition, the ecosystem management focus of CCLME would benefit from the presence of a management strategy evaluation (MSE) expertise to better support decision making that accounts for the complex linkages and interactions between and among the components of the California Current Ecosystem which affect changes in the distribution and biomass of the target species have consequent effects on ecological, social and economic systems. The wealth of information presented in the annual California Current State of the Ecosystem Report and shorter IEA version provide a suite of near-real time indicators that contribute to the Council's annual report and communicate to colleagues and the public; however, efforts should be made to streamline and automate this endeavor where ever possible.

Key (Specific) Findings and Recommendations (as reviewer has comments on)

- **Theme 1 – Management Context and Strategic Planning**

Observations:

The SWFSC is doing well in providing the scientific knowledge to address the information needs of managers and management issues. The NMFS Regional Office indicated they receive excellent support from SWFSC staff in dealing with the 120 species in the region, four management plans, ESA issues for salmon, and four sea turtles and thirty mammals with Marine Mammals Protected Act (MMPA) needs. SWFSC also plays an essential role in providing scientific support for the six regional management priorities: i) continued support for Fisheries Ecosystem Plans (FEPs), ii) support with the forage fish amendment, iii) information on climate impacts on the ecosystem, iv) information to support reduction of interactions with protected species, v) information to support reduction in inland climate impacts on salmon, vi) information on causes of pinniped unusual mortality event. The Pacific Fisheries Management Council also appreciated SWFSC efforts to be responsive in performing the research and communicating the scientific products and services such as the California Current report that provides an ecosystem context for the single species assessments, work on the forage species amendment, the development and review of the Atlantis Model used to evaluate harvest policy, work on ecosystem effects in sablefish stock assessment, and development of ecosystem indicators. The SWFSC also plays a central role in guiding the development and integration of ecosystem science in the Fishery Ecosystem Plan, the California Current Integrated Ecosystem Assessment (CCIEA), and Western Regional Action Plan (WRAP). SWFSC staff have done an excellent job of addressing the regions management's needs and building and maintaining strong relationships.

While the SWFSC has been remarkably successful in meeting the needs of managers, there is an apparent absence of an overarching strategy and objectives for ecosystem science research. Ecosystem work in SWFSC seems to be done in each of the divisions with less than optimal cross-divisional planning, integration or coordination. For example, the CCLME/CCE sampling programs produce specific suites of measurements

that are used to inform fishery stock assessments and provide management advice; however, maintaining each and every one of these measurements with declining resources is uncertain and not likely to be possible. Therefore, an outstanding challenge for the SWFSC Ecosystem Science Program will be to decide if or how existing research and fieldwork should be consolidated, and to determine the best pathway forward in this funding environment of declining resources. Much the science appears more focused on providing management advice and seems to lack strong hypothesis-driven research questions. A center-wide ecosystem strategy with well-articulated, cross-program hypotheses and division-specific objectives would help strengthen and coordinate ecosystem research with SWFSC. This approach would better maximize the potential to share resources and capabilities across centers and divisions, while providing a more holistic ecosystem approach that aims to overview and manage the system as a coherent entity. A final concern is that much of the new and innovative science (e.g., ecosystem and biogeochemical modeling) being done by the CCLME/CCE program is dependent on external funding sources and thus vulnerable to external funding decisions.

Recommendations:

1. A center-wide ecosystem strategy together with division-specific objectives would help strengthen and coordinate ecosystem research across the SWFSC
2. Development and implementation of an agreed upon SWFSC ecosystem science strategy will provide a structure to guide prioritization of research being undertaken, facilitate linkages and set up key hypotheses that require testing to ensure that these are well aligned with field data collection efforts. The California Current Regional Action Plan (RAP) can serve as an appropriate foundation for the development of such a strategic planning document.
3. SWFSC should undertake a review of its CCLME/CCE sampling programs and time series to determine the sustainability of the current suite of measurements, options for reducing (space and time frequency) or eliminating measurements, and supplementing at-sea studies with autonomous measurement systems.
4. The synthesis of ecosystem science across habitats and species and exploration of the interacting components and relationships should be encouraged.
5. The implementation of an Ecosystem-Based Fisheries Management (EBFM) will require better integration among the individual scientist's research projects and among the highly focused sampling programs to better synthesize and explore the interacting components and relationships.
6. The SWFSC should explicitly articulate the extent the science is intended to benefit both the ecosystem and the human end users to guide future research efforts and initiatives. Much of the current focus is on sustainable management or protection of individual species, as well as ways in which these species are influenced by climate variability, with less of a focus on how research findings could be used to improve the economic efficiency of, and reduce impacts by, the human users.
7. Initial progress working through the SWFSC California Current Integrated Ecosystem Assessment Team is a good start; however, SWFSC should continue to improve linkages and coordination between different research areas, and develop an integrated overview of the structure and functioning of large marine

ecosystems that draws on the existing wealth of data and scientific understanding among the various research programs within the center.

8. Ecosystem modeling should be recognized as a priority and SWFSC needs to develop approaches for providing a critical mass of individuals that can provide a structure to synthesize the independent ecosystem science activities and to develop relevant ecosystem models to support efforts in advancing ecosystem-based fisheries management approaches.
9. The SWFSC should ensure that the new management strategy evaluation (MSE) hire works with the CCLME scientists to initiate development of a MSE for CCLME/CCE system.

- **Theme 2 – Ecosystem Data**

Observations:

The SWFSC collects data on many components of the CCLME/CCE with a number of different surveys including CalCOFI, coastal pelagics, demersal fishes, pelagic juvenile rockfishes, salmon, pinnipeds, and others. Many time series and surveys go back multiple decades with the 65-year-long CalCOFI survey being the longest. The 34-year-long pelagic juvenile rockfish survey, which has been coast-wide since 2011, provides a snapshot of the pelagic ecosystem and data for key ecosystem indicators. The pinniped data (specifically California sea lions) is another spectacular data set and time series and a unique example of a time series where the diet, demography and to a limited extent the movement patterns of a marine mammal population that has recovered from earlier exploitation. The California Sea Lion demographic data set is an excellent example of the information needed to complete comprehensive stock assessment for a marine mammal in US waters, as envisioned under the Marine Mammal Protection Act (MMPA) of 1972 has been achieved. The dynamic updating of the CalCOFI state of the CA current report is another important advance. The Data Integration and Analysis Program developed by the Environmental Research Division (ERDDAP) is an excellent example of a system that provides data and products that are useful to a wide range of users. The current evaluation of the role genomics can play is a nice example of looking to new technology, whereas the use of dynamic habitat models in survey design is another example of an innovative research approach. Likewise, the efforts to develop a web-based data management system that provides data in a timely manner and useful format are commendable. Overall, while many of these datasets were initially collected focused on a single species as part of stock assessments, the fisheries science center researchers are making progress to start considering these data in the context of their environment and with respect to other species.

The reviewers recognize that data collection is both costly and time-consuming, and individual data collection programs that have been designed historically for other purposes are not always as well aligned as would be ideal to answer a new set of ecosystem science questions (i.e. measurements of physical variables and full food web variables from the same times and locations). Many of the CCLME/CCE time series appear to be legacy data sets, i.e. data continue to be collected to serve maintenance of the time series rather than for a specific scientific objective. Few of these time series have undergone synthesis and publications based on the time series are limited and the sheer volume and diversity of the data that is collected can make it overwhelming and confusing for managers and stakeholders. A challenge for the SWFSC is to determine if all these these time series represent the best investment of declining resources and evaluation of these expenditures are warranted, especially in the context of their importance for informing fishery management and as inputs for ecosystem models and a CCLME/CCE MSE. On the other hand, the observation was made that the cost to collect much of the data is relatively inexpensive since most of these efforts are colony based with low logistic costs in comparison to many of the classic fisheries stock assessments with rather expensive ship time or when compared with the cost of satellite tracking of predators.

There is also an opportunity to better connect with the US IOOS (Integrated Ocean Observing System) as efforts are underway to determine what components are necessary to develop the biological components of an ocean observatory. Many of the SWFSC measurements in the currently carried out in the CCLME/CCE could be

analyzed to provide insight into which measurements are key, but also represent a wealth of existing data sets and time series that can and should be incorporated in IOOS that would not only be helpful to IOOS, but could help justify the sustaining these time series.

Recommendations:

1. The SWFSC should conduct a review of all the cruises and data collection programs, and use model-based Observing System Experiments (OSEs) to explore ways to develop a more integrated and efficient ecosystem survey program, including sampling, processing, and timely data analysis, while still continuing to meets the species-specific information needs.
2. SWFSC investigators working in the CCLME/CCE would benefit from collaboration with other NMFS investigators, especially those with upper trophic level expertise, to provide a better context for the study of individual species within the ecosystem and with respect to other species.
3. The SWFSC should undertake syntheses of CCLME/CCE data sets within and across its research programs and engage in comparative studies to place its long-term data sets into a broader context.
4. The SWFSC should partner with US IOOS on the design of the ecosystem science components of an ocean observatory system and on assessments of the approaches and value of animal tracking to understand the distribution and movement of marine species.
5. The SWFSC should move beyond just the dynamic updating of the CalCOFI state of the California Current Report and generate a very short high level summary, using plain language, that could be used as a broader communication tool, and importantly as a rapid succinct update for key stakeholders, managers and policy makers.

- **Theme 3 – Ecosystem modeling and analysis**

Observations:

The SWFSC research presented was largely focused on single species analyses or links between population parameters and the environment. There is excellent work going on to examine ecosystem dynamics from a bottom-up perspective and a top-down perspective. Much of the CCLME/CCE dynamics and modeling research starts with the physical system of upwelling dynamics in terms of spatial and temporal dynamics, moves on to biogeochemical cycling and impacts on biology, to fishery stock assessment and some high trophic species including nonlinear responses and upper trophic level population dynamics. The biophysical modeling is used to mechanistically understand and predict critical processes and dynamical responses to present stressors and the additional stressors from climate change. The SWFSC salmon modeling and dynamics research is doing an excellent job in integrating processes, observations, and models. Habitat models using environmental data in generalized additive models (GAMs) are widely used for applications ranging from demersal fishes to highly migratory species. Habitat models also serve as the basis for work to produce near-real time spatial maps for whales and bycatch species with the goal of employing dynamic ocean management to reduce various types of interactions with these species.

The SWFSC CCLME/CCE modeling activities provide important results; however, it appears as though many of these efforts being implemented in isolation both within the center and relative to the external community in other federal laboratories or at academic institutions. There needs to be more dynamical modeling that integrates marine ecosystems from lower trophic level species to upper trophic level species and then back again using integrative models that link across multiple trophic levels and are couple to environmental conditions. The lack of this perspective was reflected in the absence of research focused on a single food web description of the California Current either in the form of an energy flow or food web model (Ecopath Model or similar) from plankton to apex species and also includes various fishery removals. The panel was concerned by what appears to be an insufficient focus on a conceptual understanding and thinking about the California Current from either a trophic or an energy flow perspective. In particular, to move the SWFSC CCLME/CCE science to the next level, there needs to be a critical mass of modeling expertise able to apply coupled physical-biological models of the California Current at the appropriate spatial and temporal scale to address relevant marine ecosystem dynamics and fisheries management questions for the region. Such a capability would play an important role as an integrated and relatively rigorous scientific foundation and knowledge base to support climate-smart ecosystem decision-making. While an Atlantis Model for California Current system with full spatial and trophic resolution has been built in collaboration with the NWFSC, it is unclear how tightly this work is linked to the SWFSC research efforts. Extensive application of such a management strategy evaluation ecosystem modeling system for the California current would not only provide a context for mechanistic understanding of the energy flow in the CCLME/CCE and posing questions for future research, but the widespread application of such a modeling capability would be extreme useful to evaluate the current strengths and challenges in SWFSC ecosystem surveys. Furthermore, ecosystem-based fishery management for the CCLME/CCE would be significantly advanced by a management strategy evaluation modeling capability that links across climate, ecosystem, circulation, fishery, harvest and socioeconomic models. The level of reimbursable funding received for ocean modeling and dynamic ocean forecasting of risk, makes these innovative modeling activities more vulnerable to external funding decisions than if this research was more fully supported internally.

Recommendations:

1. The SWFSC should develop a critical mass of ecosystem modeling with the scientific expertise to run integrative ecosystem models for the CCLME/CCE that can link across multiple trophic levels and couple to environmental conditions, can be used to evaluate both bottom-up versus top down controls on the CCLME/CCE and various subcomponents, and can be applied to assess the strengths, weaknesses and opportunities in SWFSC ecosystem surveys.
2. The SWFSC should develop a conceptual model for the CCLME/CCE that includes links across system components that can better articulate food webs, models of energy and nutrient flow. Such a conceptual model for the CCLME/CCE would be extremely valuable for developing hypotheses about how the California Current works and guiding future prioritization of research on important components of the ecosystem.
3. SWFSC should make a greater effort to make better use of the world-class, research-quality observations and mechanistic understanding of critical biogeochemical processes, as well as other results of their ecosystem science

research, to evaluate, validate and improve dynamical marine ecosystem modeling.

4. The SWFSC should hire a management strategy evaluation (MSE) researcher and ensure this scientist has the time and resources to develop a MSE for the CCLME/CCE.
5. The SWFSC should make further use of the California Current System implementation of the Atlantis model for a broad range of marine ecosystem dynamics and fisheries management questions. A few examples of the application of the Atlantis Model for California Current system would be to help improve the management of forage fish to achieve ecosystem management goals, to integrate and interpret the suite of indicators presented in the California Current Ecosystem Report, to identify and forecast current and future risk and multi-stressor tipping points for the CCLME/CCE and subcomponents, and to optimize CCLME/CCE Trust Resource management decisions.

- **Theme 4 – Incorporation into Management**

Observations:

The SWFSC has successfully put in place several mechanisms to facilitate the translation of marine ecosystem science into management decision-making. The California Current Integrated Ecosystem Assessment (IEA) is recognized as a flagship of the national IEA program, serving to communicate ecosystem science and climate information to managers and stakeholders, and the general public. The efforts to translation of marine ecosystem science, data and findings to guide management decisions and policies in the CCLME/CCE are valued and well received by the Pacific Fisheries Management Council and NOAA Fisheries West Coast Region leadership. The level of reimbursable funding received for targeted research from mission agencies such as Navy, BOEM and others, while a risk in terms of vulnerable to external funding decisions, is a strong, independent endorsement of the quality of work that is being done by the SWFSC to support regional policy, planning and decision making.

While the SWFSC has made good use of analyses and correlative/statistical models of CCLME/CCE system dynamics to inform fishery and trust resource management practices, more mechanistic, process-based bio-physical regional models will be needed to evaluate scenarios for future conditions impacting commercially important marine species in a changing climate and to characterize the risks to habitats in response to the complex dynamics of multi-stressor marine ecosystem tipping points. The marine ecosystem vulnerability assessments that were part of the regional action plan seemed to focus more on the impacts of robust, high probability changes in the biogeochemical environment in the evaluation of risk with less emphasis on potentially high impact, low probability change. When communicating risk, there is an additional need to articulate both the predictability limits and inherent uncertainty when describing the likely impact of future global change.

Recommendations:

1. The SWFSC should accelerate efforts to move towards mechanistically based biophysical modeling approaches for the CCLME/CCE to inform decision makers of options and risks in dynamic, multi-stressor, environmental conditions under the influence of a changing climate.

2. The SWFSC should implement a management strategy evaluation (MSE) for the CCLME/CCE that incorporates socioeconomic considerations to better inform marine ecosystem resource management and decision-making.
3. The SWFSC should make further use of the California Current System implementation of the Atlantis model to further consolidate and quantify key relationships and mechanisms driving the system, as a platform for informing decision making.
4. To inform policy, planning and decision making on future risk, the SWFSC will need to develop effective ways to communicate to decision makers to help them understand how they should interpret the predictability limits in modeling studies as well as the inherent uncertainty embedded in analyses and findings in scientific assessments.
5. SWFSC efforts to translation of ecosystem science, data and findings to guide regional management decisions and policy making should be continued and expanded to include socioeconomic impacts and considerations.

- **Theme 5 – Communication and Peer Review**

Observations:

The SWFSC intellectual contributions from the CCLME/CCE research program have been impressive, drawing on a broad range of activities have been sustained over many years. The SWFSC produces the annual *The State of the California Current Report* that provides an update for a suite of physical and biological time series which monitor vital signs of the CCLME. The State of the California Current Report is recognized as an excellent communication product that provides an ecosystem science perspective on the regional environmental conditions impacting CCLME marine habitat and living marine resources. This information is consolidated into a more concise knowledge product that is used by Pacific Fisheries Management Council to guide the formulation of policy, planning and decision-making. More broadly, the SWFSC researchers working on the CCLME/CCE have developed and maintained important partnerships with a spectrum of stakeholders ranging from state regulatory agencies, federal agencies, other scientific institutions, the academic community and non-governmental organizations. In particular, the CalCOFI component of the overall research enterprise is a well-recognized and respected scientific activity, integrating efforts by the SWFSC, the State of California, and various academic institutions (especially Scripps Institute of Oceanography).

The SWFSC scientists working on the CCLME/CCE are well-regarded leaders in their respective fields; however, the broader scientific impact of the CCLME science beyond the input to the Pacific Fisheries Management Council remains somewhat limited. While the annual State of the California Current System report is a useful summary written for a general audience of CCLME relevant issues, compiling the report requires considerable time and effort, which may not be the best use of personnel time. An extensive report also might not be the best communication approach for engaging stakeholders and other groups. The efforts to transition components of the report to online supplemental information with the option for updates keep the report current is a positive development that should improve perception that the report is timely and useful. There is a critical need for SWFSC leadership and communications/media personnel to develop strategies for enhanced media dissemination of this annual report, and more generally a wider and higher profile dissemination of CCLME/CCE science and research

findings. Paralleling the enhanced communication strategies, the publication of integrative and synthesis papers that present high-impact overviews of the science being conducted should be made a high priority across the CCLME/CCE research program. Another concern is that the peer-reviewed publication record was quite variable among staff with some publishing regularly and others collecting and compiling long and impressive research-quality CCLME/CCE time series that remain unpublished and thus unknown to the broader research community. This type of issue can be addressed by allocating the time and resources for SWFSC staff to be able to produce timely publications describing their research, and in particular papers documenting and interpreting these important and unique datasets being collected by the CCLME/CCE research program.

Recommendations:

1. The SWFSC should develop a strategy that will prioritize time and resources to facilitate elevating the scientific visibility of the CCLME/CCE research program.
2. The SWFSC should make publication of synthesis and integrative CCLME/CCE studies a high priority that is supported in terms of time and resources for research staff to work on these professional development activities.
3. The SWFSC should ensure that the incredibly valuable, long time series of CCLME/CCE data are adequately described and analyzed in publications so the resulting scientific insights and advances in understanding are broadly shared with and understood by the external research community.
4. The SWFSC should develop a social media strategy that will engage stakeholders and the general public in the exciting science and advances in understanding being produced by the CCLME/CCE research program.
5. The high successful annual State of the California Current System report should be transitioned to a web-based system with the option for real-time updates.
6. Strategies for dissemination of the State of the California Current System report are needed so that it reaches the appropriate readership and is perceived as a timely and useful product such as a 1-2-page synthesis to disseminate the report findings to a much broader audience.

Appendix 2

Individual Panel Members' Reports

Reviewer 1 - Report on Program Review of Ecosystem Science
Science Center: Southwest Fisheries Science Center (SWFSC)
Address: La Jolla, CA
Dates: 18-22 April 2016

I. Antarctic Ecosystem Research Division

Background

This portion of the report focuses on the Antarctic Ecosystem Research Division (AERD). Background information relevant to the review comments is:

- The AERD sits between stakeholders (e.g., fishing industry) and the Scientific Committee of the Commission for the Conservation of Antarctic Living Marine Resources (CCAMLR), which is an international commission that sets conservation measures that determine the use of marine living resources in the Antarctic.

- AERD personnel lead, attend and participate in CCAMLR workings groups, the Scientific Committee, and contribute to the U.S. delegation that supports the work of the Commission.

- AERD's activities are developed around its vision that includes '…observing the Antarctic ecosystem, interpreting observed changes in the context of fishing and climate change effects, and predicting potential impacts of fishing and climate change in the future'.

- The U.S. Antarctic Marine Living Resources (AMLR) program has collected at-sea data sets that extend for more than 25 years and land-based data sets that extend for more than 30 years.

- AMLR undertakes an annual cruise (now a winter cruise) to the South Shetland Islands/Bransfield Strait region and maintains land-based sampling at sites on Cape Shirreff and King George Island.

- The reduction in field program time starting in 2017 provides an opportunity to assess and revise the AMLR sampling strategy and AERD resource allocation.

- The AMLR program underwent a review in 2009. Most of the recommendations from this review have been incorporated into the AMLR program. Those not incorporated, such as the hiring of an oceanographer, were deemed not feasible because of lack of resources.

- The SWFSC has initiated hiring of an individual with Management Strategy Evaluation (MSE) expertise.

General Observations and Recommendation

The research undertaken by AERD has contributed to understanding of Antarctic ecosystem processes, the ecological effects of harvested species on dependent and related species, and ecosystem based fishery management for Antarctic resources. The inputs to CCAMLR based on the AMLR data and analyses have significantly contributed to and facilitated development of Ecosystem Based Fishery Management (EBFM) for Antarctic marine living resources. The success of AERD is remarkable because it has been achieved in spite of declining resources, limited personnel and truncated field programs. AERD is mature scientific program that is at a critical juncture. Continuation in its current form is unlikely and attempts to do so will compromise the ability of the program to maintain high quality science, meet its management mandate, and provide well-considered advice to CCAMLR. The comments in the following sections are intended to highlight areas that need attention from the SWFSC and AERD to maintain the quality of the program, and also provide the ability for AERD to evolve to meet future demands and challenges.

Key (Specific) Findings and Recommendations (as reviewer has comments on)

Theme 1 – Management Context and Strategic Planning

Observations

AMLR has a mandate to provide scientific advice to CCAMLR to inform fisheries management decisions. The feedback management approach being developed by AERD uses ecosystem-based information to adjust krill catch limits so that dependent predator populations do not suffer harm from fishing is innovative. This approach fits the management need to determine local allocations for krill catches (i.e. small scale management units). The approach now under development by AERD does not explicitly account for climate and environmental variability and seems overly complex.

AERD has a vision statement to guide its research and its research programs are designed to contribute to this vision. Hypothesis-driven research may be implicit in individual research projects, but hypotheses that integrate across AERD programs are not apparent. Research programs developed around hypothesis-driven research are more likely to yield results that can be compared across research efforts and provide comparisons with other systems.

The ecosystem and management focus of AERD would benefit from the use of a MSE. The complex linkages and interactions between and among the components of the Antarctic ecosystem that affect changes in the distribution and biomass of the target species have consequent effects on ecological, social and economic systems. A MSE will integrate these systems and their interactions with a consistent set of rules, allow primary pathways to be identified, and point to the critical controlling linkages. Expertise in ecosystem modeling within AERD is critical to the development of a MSE focused on the Antarctic ecosystem.

AERD has been operating in an environment of declining resources and support for several years. AERD cannot continue with the operational model that has been used in the past and maintaining the suite of measurements currently done by the AMLR program is not likely to be possible.

Recommendations to address issue

- Future development of the feedback management should consider a less complex approach that incorporates climate and makes use of proxies that are readily obtainable.
- AERD should develop set(s) of hypotheses to guide its research programs and allow comparability with other systems.
- AERD should work with the SWFSC Director to ensure that a MSE for the Antarctic system is a priority for the new hire.
- AERD should work with the SEFSC Director to develop a strategy for providing expertise in ecosystem modeling.
- AERD should initiate development and implementation of an operational model that relies less on at-sea and land-based measurements and has a stronger focus on synthesis and modeling studies.

Theme 2 – Ecosystem Data

Observations

The recent reduction to two cruises in three years and shortened land-based field seasons will significantly impact the time series that have been collected by AMLR over the last 30+ years, which are critical to CCMALR deliberations and decisions.

AERD has made a commendable effort to make data accessible on the web and is making plans to add more data sets and improving access. The reduction in field time in the next few years may provide additional resources and time to facilitate data QA/QC and data availability. Both will encourage use of AMLR data by a wider science community and provide added value for the data that have been collected.

The AMLR program has a wealth of data sets, some of which are approaching time scales that can be used to address climate issues. The AMLR data are not particularly visible within the Southern Ocean community, perhaps because of prior difficulties in obtaining these data through CCAMLR. As a result, the AMLR data have limited impact in scientific discussions, development of Southern Ocean programs, and informing Southern Ocean observing systems.

Recommendations to address issue

- Field programs and data sets must be prioritized and adjusted so that critical data sets are maintained.
- Modeling expertise that can help with examining and identifying critical data sets should be developed within AERD.
- Collaborative field efforts with other nations that can potentially mitigate gaps in time series data sets (more probable for land-based data sets) should be pursued.
- AMLR should undertake a review of its sampling program to determine the sustainability of the current suite of measurements, options for reducing (space and time frequency) or eliminating measurements, and supplementing at-sea studies with autonomous systems (e.g., gliders) and moorings (e.g., acoustic moorings).
- AERD should examine the feasibility of reallocating personnel time and program resources to support data assessment, data availability and maintenance of a web-based data management system.
- AMLR should undertake syntheses and comparative studies of its long-term data sets and publish these in as a book (e.g., AGU Antarctic Research Series) and/or special issue(s) of a peer-reviewed journal (e.g., *Deep-Sea Research II*).

- The SWFSC should provide adequate support to AERD to ensure accessibility, integrity and quality of the AMLR data sets.
- The SWFSC should provide resources and personnel time to develop dedicated publications for the AMLR data.

Theme 3 – Ecosystem modeling and analysis

Observations

The at-sea and land-based data sets collected by the AMLR field programs provide unprecedented time series of ecosystem processes in the northern part of the west Antarctic Peninsula. Aspects of these data have been reported in a range of peer-reviewed publications. The impact of these data sets would be significantly improved by a synthesis, comparisons with similar data sets from other areas of the Antarctic, and comparative studies to place them within a broader context. The need to link this synthesis to the program mandate for management is recognized.

The AERD ecosystem-based focus would be significantly advanced by the availability of circulation, biogeochemical and food web models that are implemented for the regions of interest to the program. Linking these models with fishery harvest, management, and economic models could provide inputs to make the feedback management process more robust. A suite of models that link across environment-ecosystems-socioeconomic-management will enhance the value of the AMLR data sets, provide a consistent framework for developing management advice, and allow testing the effects of a range of scenarios on harvesting and fishery management. Providing this expertise is critical for AERD.

It is recognized that efforts are underway by the SWFSC to hire an individual with MSE expertise. The SWFSC is planning an additional hire(s) with ecosystem modeling expertise. In the short term, modeling expertise can be obtained via collaborations and through hires of postdoctoral researchers.

Recommendations to address issue

- The AERD should initiate a synthesis of the AMLR data sets and use this as a basis for comparative studies.
- The SEFSC Director should ensure that the MSE hire has the time and resources to work with AERD personnel on a MSE for the South Shetland Islands ecosystem.
- The AERD should work with the SWFSC Director to develop a plan for hiring an ecosystem modeler with a focus on the Southern Ocean.
- The AERD should develop collaborations with U.S. academic institutions and international research centers (e.g., British Antarctic Survey, IDEAL Center, Chile) that have Southern Ocean modeling expertise.
- AERD should explore possibilities for obtaining resources for hiring postdoctoral researchers with modeling expertise.

Theme 4 – Incorporation into Management

Observations

The AERD science is central to the development of ecosystem-based management for Antarctic marine resources and AERD personnel provide important leadership within CCAMLR for its development. Advice provided by AERD has been central to achieving consensus on complex international negotiations about management of marine resources. Development of a feedback management approach

is part of continuing AERD contributions to ecosystem-based management. The complexity of the feedback management approach may make achieving consensus and adaptation by CCAMLR problematic.

AERD personnel play a central role in development of MPAs in the Southern Ocean, especially the current effort to develop a MPA for the Ross Sea. Considerable time and effort have been expended on developing, revising and negotiating the Ross Sea MPA plan. Much of this effort seems to have focused on dealing with political interests of various nations in order to develop a plan that can achieve consensus. The commitment by AERD personnel to the development of a Ross Sea MPA is commendable. However, the Ross Sea is not a focus for the AMLR program and efforts with the Ross Sea MPA divert AERD personnel and resources from more directly relevant activities. The development of MPAs in the Southern Ocean is an important focus for the U.S. State Department. Resources that support U.S. participation in MPA planning should come the State Department, particularly because much of this planning is motivated by geopolitical concerns rather than by science issues.

Recommendations to address issue

- As noted above, future development of the feedback management should consider a less complex approach that will make achieving consensus more likely.
- AERD personnel should continue to provide science inputs for Southern Ocean MPA planning and implementation but not at the level that impacts other mandates and priorities.
- The U.S. State Department should be the lead for all geopolitical negotiations surrounding Southern Ocean MPAs.
- The AERD should consolidate its efforts to focus on the South Shetland Islands region of the west Antarctic Peninsula.

Theme 5 – Communication and Peer Review

Observations

The AMLR data sets and intellectual contributions by AERD personnel are critical to CCAMLR. The AMLR program and scientists are well respected within the CCAMLR community. However, outside of this community the national and international impact of AERD/AMLR is limited, even though it is a mature program. Time and funding constraints limit the ability of AERD personnel to participate in relevant meetings (e.g., 2016 Ocean Sciences Meeting), conferences and workshops and to serve on national and international committees (e.g., IMBER Integrating Ecosystems and Climate Dynamics (ICED) in the Southern Ocean) and working groups, outside of CCAMLR.

Publications in peer-reviewed journals show that AERD research in general and the AMLR program in particular is of high quality. However, these publications provide only limited results and have limited impact (a quick look at Google Scholar citations for some AMLR-related papers suggests fewer than 10 citations per year). Dedicated special issues and/or books will help communicate program results to a wider community and have a longer-term impact.

The working papers and background documents submitted to CCAMLR undergo peer review by working groups and committees. Considerable time is invested in preparing and revising these papers. However, few of these transition to peer-reviewed publications in scientific journals. The reduction in the AMLR field program time

provides an opportunity to redirect time and effort to developing some of these papers into peer-reviewed publications.

Recommendations to address issue

- AERD should prioritize time and resources to facilitate elevating the visibility of the program through participation in national and international activities outside of CCAMLR.
- Participation by AERD personnel in a wider range of scientific meetings, advisory committees, and activities should be encouraged and resources allocated to support these activities.
- AMLR should undertake syntheses and comparative studies of its long-term data sets and publish these in a book (e.g., AGU Antarctic Research Series) and/or special issue(s) of a peer-reviewed journal (e.g., *Deep-Sea Research II*).
- AERD should consider strategic approaches for providing input to CCAMLR so that CCAMLR-related papers can transition into publications for peer-reviewed scientific publications.

Other

Observations

Historically the AMLR program had a strong and viable partnership with the NSF Office of Polar Programs (now Division of Polar Programs) that provided logistical and financial support that was critical to maintaining some of the AMLR time series (e.g., penguins) and field camps. This partnership has eroded in recent years possibly because of the change in the program manager for the Antarctic Organisms and Ecosystems program from a permanent to rotator position. The current structure at NSF Polar Programs does not provide the continuity that existed previously. Re-establishing a partnership with NSF Polar Programs might provide support for some of the AMLR field activities that will be lost with the upcoming reduction in field resources.

Recommendations to address issue

- The SWFSC Director should initiate discussions with the Head of the NSF Directorate of Geosciences to reassess the NSF-AMLR partnership.

II. California Current Large Marine Ecosystem

Background

This portion of the report focuses on Ecosystem Science in the California Current Large Marine Ecosystem (CCLME). Background information relevant to the review is:

- Ecosystem studies of the California Current System are distributed throughout four divisions of the SWFSC – Environmental Research Division, Fisheries Ecology Division, Fisheries Resources Division, Marine Mammal and Turtle Division.

- CCLME data collection programs are diverse with major efforts focused in the California Cooperative Oceanic Fisheries Investigations (CalCOFI), fish (e.g., pelagic, demersal) surveys, and pinniped surveys.

- Many of the CCLME data sets extend for more than 30 years; the CalCOFI data extend for longer.

- The CCLME data and results provide inputs to the Pacific Fisheries Management Council and these are held in high regard.

- Many CCLME activities are mandated because of legislative and regulatory constraints imposed by the Magnuson-Stevenson Act, Marine Mammal Protection Act, the Endangered Species Act, and many others.

- The California Current Integrated Ecosystem Assessment provides a focus and plan for implementing ecosystem-based fisheries management.

- A range of modeling approaches has been implemented for the California Current system.

- The SWFSC has initiated hiring of an individual with Management Strategy Evaluation (MSE) expertise.

General Observations and Recommendation

The SWFSC research programs gave contributed to understanding of CCLME ecosystem processes. There is a commitment from the SWFSC for implementation of Ecosystem-based Fishery Management (EBFM) for the CCLME.

The CCLME research program is remarkably successful. However, in a time of declining resources it is appropriated to undertake a critical review of investments in sampling programs and maintenance of time series and consider reallocation of resources to other efforts such as ecosystem modeling, synthesis and integration studies, MSE development, and use of autonomous measurement systems.

The comments in the following sections are intended to highlight issues for consideration by the SWFSC and divisions so that the quality of the CCLME program is maintained and future demands and challenges can be met.

Key (Specific) Findings and Recommendations (as reviewer has comments on)

Theme 1 – Management Context and Strategic Planning

Observations

The CCLME sampling programs provide specific suites of measurements that are used to inform fishery stock assessments and provide management advice. Maintaining these measurements with declining resources is uncertain and not likely to be possible.

Much of the new and innovative science being done by the CCLME program is dependent on external funding sources and is vulnerable to the vagaries of funding decisions. This is of particular concern because the ecosystem and biogeochemical modeling activities seem to be dependent on this external funding.

The CCLME program is focused on providing information that can inform fisheries management. The program is successful in doing this as evidenced by remarks provided by the fisheries management council. However, it seems that the

research programs in the various divisions, and even in the same division, operate in isolation from one another. Better integration of data and research programs will improve the advice provided for fishery management, as well as advance understanding of the CCLME.

Hypothesis-driven CCLME research programs are focused around providing management advice and seem to lack a hypothesis-driven basis. Integration of CCLME research within and across divisions would be facilitated by across-program hypotheses. Hypothesis-driven research will also help with comparative studies, such as with other upwelling systems that will place the CCLME results into a larger context.

Understanding climate and its effects on the CCLME ecosystem, fisheries, and management would be facilitated by the availability of a MSE, which would also provide a framework for integrating and synthesizing across the CCLME program.

Recommendations to address issue

- CCLME should undertake a review of its sampling programs and time series to determine the sustainability of the current suite of measurements, options for reducing (space and time frequency) or eliminating measurements, and supplementing at-sea studies with autonomous measurement systems.
- The SWFSC should recognize ecosystem modeling as a priority and develop approaches for providing a critical mass of individuals with this expertise and stable long term funding.
- The SWFSC should ensure that the new MSE hire works with the CCLME scientists to initiate development of a MSE for this system.
- The CCLME should develop hypotheses that integrate its individual research programs and allow comparability with other systems, especially other upwelling systems.

Theme 2 – Ecosystem Data

Observations

The CCLME supports collection of many and varied data sets and time series. A systematic synthesis of individual data sets and across-data set synthesis is needed, as is placing these data within a broader context through comparative studies. For example, CCLME pinniped data could be compared with similar data sets collected by the Alaska Fisheries Science Center and the AMLR program. This type of analysis should reveal where gaps exist, which data sets serve a needed scientific objective, and what sampling strategies are needed.

Many of the CCLME time series appear to be legacy data sets, i.e. data continue to be collected to serve the time series rather than for a specific scientific objective. Few of these time series have undergone synthesis and publications based on the time series are limited. These time series may not be the best expenditure of declining resources and evaluation of these is needed, especially in the context of their importance for informing fishery management and as inputs for ecosystem models and a CCLME MSE.

The efforts to develop a web-based data management system that provides data in a timely manner and useful format are commendable. The Data Integration and Analysis Program developed by the Environmental Research Division (ERDDAP) is an excellent example of a system that provides data and products that are useful to a wide range of users.

Recommendations to address issue

- CCLME should undertake syntheses of data sets within and across its research programs.
- CCLME should initiate comparative studies that will place its long-term data sets into a broader context.
- CCLME should undertake a review of the time series data sets to determine if they address a scientific need and if they should continue to be collected at the present space and/or time resolution.
- CCLME should continue support of a web-based data management system and ensure that resources for the system are sustainable in the long term.

Theme 3 – Ecosystem modeling and analysis

Observations

The CCLME would benefit from comparative studies with other upwelling systems, especially in terms of developing scenarios for responses to natural and anthropogenic climate change. This comparative analysis would provide a larger context for the CCLME program results.

The modeling activities of CCLME appear to be focused on upwelling circulation dynamics, biogeochemical cycling, fishery stock assessment, and upper trophic level population dynamics. These models provide important results but each seems to be implemented in isolation. These models also seem to be isolated from similar modeling studies underway at academic institutions. Integrative models that link across multiple trophic levels and couple to environmental conditions are needed to evaluate both bottom-up versus top down controls on the CCLME.

Individual components of the CCLME program provide useful and interesting data and results. However, it is not obvious that these components are part of an overall larger conceptual view of the California Current System. Developing a larger view will help with setting priorities for observational programs, developing approaches for system integration, and providing advice for management. The conceptual model developed for salmon can provide guidance for a CCLME model.

Ecosystem-based fishery management for the CCLME would be significantly advanced by a MSE that links across climate, ecosystem, circulation, fishery, harvest and socioeconomic models. The MSE would enhance the value of the CCLME sampling programs, allow evaluations of scenarios designed to test the effects of harvesting and fishery management policies and climate on fishery stocks, and provide guidance on the relative roles of fishing and climate in affecting stock abundance of fisheries and dependent species.

Efforts are underway by the SWFSC to hire an individual with MSE expertise. Incorporation of ongoing modeling activities and additional hires with ecosystem modeling expertise are critical to the success of a CCLME MSE. A version of the Atlantis model (a MSE) seems to have been implemented for the California Current System, but results and recommendations based on this model were not obvious to the review committee. Better integration of this MSE into CCLME science is needed.

Recommendations to address issue

- The CCLME should initiate comparative studies with a focus on comparisons to other upwelling systems.
- The CCLME should develop an integrative modeling program that brings together existing models and links these to observational programs.

- The CCLME should develop a conceptual model for the CCS that links across system components and implement this through a MSE.
- The SEFSC Director should ensure that the MSE hire has the time and resources to develop a MSE for the CCLME.
- The CCLME should work with the SWFSC Director to develop strategies for hiring ecosystem modelers so that a critical mass of expertise is developed.
- The CCLME should make better use of the California Current System implementation of the Atlantis model and incorporate this into the activities of the new MSE hire.

Theme 4 – Incorporation into Management

Observations

The CCLME makes good use of correlative/statistical models for providing advice for fishery management. However, evaluating scenarios for projections for future conditions requires mechanistically based models.

The CCLME has developed several approaches to facilitate the translation of ecosystem data and results into management decisions and policies and these inputs are valued and well received by the fishery management council. These activities should be continued and expanded to include socioeconomic considerations.

As noted above, a MSE is important to improving advice that is provided to fishery management councils.

Recommendations to address issue

- The CCLME should move towards mechanistically based modeling approaches.
- Implementation of a MSE for the CCLME will facilitate management advice that incorporates socioeconomic considerations.
- A MSE for the CCLME system is a priority as is better integration of the Atlantis implementation for the California Current System.

Theme 5 – Communication and Peer Review

Observations

The intellectual contributions from the CCLME are excellent and have been sustained over many years. The CCLEM has developed and maintained important partnerships with stakeholders, state regulatory agencies, federal agencies and other scientific institutions. The program and scientists are well respected. However, the broader scientific impact of the CCLME is limited. Publication of integrative and synthesis papers should be given a high priority, with time and resources allocated to support these publications.

A strategy for wider dissemination of program results (e.g., dedicated publications, special sessions) and engagement of the public (e.g., via social media) should be developed. The latter is particularly important for developing a user community that depends on information from CCMLE. CCMLE should work with the SWFSC Director and communications/media personnel to develop strategies that will consistently engage the public.

The annual State of the California Current System report provides a useful summary of issues relevant to the CCLME. The report is written for a general audience and provides important input to the Fishery Management Council. However, compiling the extensive report requires considerable time and effort, which may not be the best use of personnel time. Also an extensive report might not be the best approach for

engaging stakeholders and other groups, as suggested by the small number of citations to the report. Efforts are underway to transition components of the report to online supplemental information and to have the option for updates, which will allow the report to more up to date. These are positive developments, and should help with the perception that the report is timely and useful. There is a critical need for a media dissemination strategy for the report.

Recommendations to address issue

- CCLME should develop a strategy that will prioritize time and resources to facilitate elevating the scientific visibility of the program.
- Publication of synthesis and integrative studies should be given a high priority and supported.
- CCLME should develop a social media strategy that will engage stakeholders and the general public.
- The annual State of the California Current System report should be transitioned to a web-based system with the option for real-time updates.
- Strategies for dissemination of the report are needed so that it reaches the appropriate readership and is perceived as a timely and useful product.

Reviewer 2 - Report on Program Review of Ecosystem Science
Science Center: SWFSC
Address: La Jolla, CA
Dates: 18-22 April 2016

Background

An overview of the Ecosystem Science program at the SWFSC was presented over a three-day period. The first part of the review focused on the Antarctic Ecosystem Research Division (AERD) which involves participating in the Commission for the Conservation of Antarctic Living Marine Resources (CCAMLR) working groups tasked with conservation and management of marine living resources in the Antarctic. The U.S. Antarctic Marine Living Resources (AMLR) program is also responsible for long-term land- and sea-based data collection programs to monitor the status of the Antarctic ecosystem.
The second part of the review focused on the Regional Office Ecosystem Science in the California Current Large Marine Ecosystem (CCLME). The ecosystem science program forms the basis for moving to ecosystem-based approaches to management, and provides important inputs to the Pacific Fisheries Management Council, as well as assessments of the status of marine mammal and endangered species populations. The program includes substantial long-term data collection programs such as the California Cooperative Oceanic Fisheries Investigations (CalCOFI), fish surveys, and pinniped surveys.
The structure of the review allowed sufficient time for asking questions after each presentation, and members of the public were also able to ask questions.

General Observations and Recommendation

Overall the SWFSC is to be congratulated on doing an outstanding job in delivering world-class science to inform decision making. It was a pleasure listening to the very well-presented clear presentations, and to see the dedication and enthusiasm of the staff. The lab has responsibility for a very broad range of topics, from the Antarctic to the California Current Large Marine Ecosystem (CCLME), as well as fisheries, salmon stocks, marine mammals, migratory species and climate change considerations. The very long and rich data time series contribute to the lab's stellar reputation. These also provide a much needed foundation (that is lacking in most other parts of the world) for implementing ecosystem science and beginning to respond to climate change. This is particularly relevant because the two primary study areas (the Antarctic and CCLME) are subject to major climate influences and include species that are known to respond dramatically to changes in environmental conditions.

There is clear evidence of ecosystem science threads being embedded in much of the science that is being done, but a less clear picture emerged of an overall strategy to interweave these threads and ensure the sum is greater than the individual parts. Whilst recognizing that this is largely a function of an ongoing transition away from a more narrow focus to a more integrated ecosystem approach, there might be merit in more formally developing a comprehensive ecosystem strategy for the Center. This could link the Antarctic ecosystem science with the regional ecosystem science to ensure that synergies and complementary research are better integrated and contributes to the collective learning. Although a broad ecosystem strategy would presumably sit under the WRAP, it would nonetheless be advantageous to separately agree on an ecosystem

strategy as a way to guide prioritization of research being undertaken, facilitate linkages and set up key hypotheses that require testing to ensure that these are well aligned with field data collection efforts.

The West coast Regional Action Plan (WRAP) under development is an excellent and much needed umbrella to integrate all the research and co-ordinate the provision of climate-related information to support decision making. The action plan is well designed but has yet to be implemented to demonstrate its success, and to ensure the latter it will be necessary that resources are available to make the necessary linkages with the individual research efforts, especially given that many of these are stretched to complete current priorities.

One of my key recommendations is to create at least one more ecosystem modeler position with responsibility for synthesizing the Center's research and to provide a more holistic overview and understanding of the CCLME, in a way that links the physical environment, full foodweb from plankton to top predators, as well as human and socio-economic considerations. The ecosystem modeler would need to work closely with all the research groups, drawing on the extensive insights of the individual researchers, to assist in quantifying the role of physical drivers in influencing ecosystem dynamics from the plankton through to the whales, and utilizing and linking the rich data sets available (particularly CalCOFI and the predator monitoring data).

A related recommendation is to encourage lead scientists to devote time to consolidating existing research and synthesizing outputs and linkages with the Center's other research groups – there was clear evidence of excellent high quality science, but a need to capitalize on the wealth of data and understanding to provide a more integrated overview to support advancement of the ecosystem approach as well as understanding of future climate change impacts. Details of the California Current Atlantis model were not presented (which is understandable), and although the existing Atlantis model goes some way to addressing the recommendation above, and is a suitable tool for a number of purposes, this could be complemented by other models. Ideally a range of complementary models with different focus (including tactical vs strategic) and different spatial and temporal scales and resolution should be developed. For example, there is an additional need for more focused regional scale coupled physical-biological models that draw on the existing wealth of data and provide detailed insights into system functioning and future changes. Forage fish are a natural starting focus point for a coupled physical-biological model. There is also considerable opportunity to develop intermediate complexity models that are fitted to available data. Qualitative conceptual models would also be useful as a starting point to synthesize important connections in the system.

A key impression across most of the research areas is that as resources have shrunk, staff are overstretched, yet their commitment means that they are attempting to maintain the same activities at the expense of leaving time for their own personal development. It would be advantageous to reassess workplan priorities to free up some time for staff for personal development activities such as publishing in the peer-reviewed literature, broadening collaborations, attending scientific conferences and developing a hypothesis-based approach as a focus for ongoing data collection.

The Center is to be commended for its collaboration with Scripps and role in maintaining the CalCOFI series, which is a unique and comprehensive series with considerable

value. The value of these data will only increase as climate change drives fundamental changes in this and other systems. It is therefore important to maintain this long data series, but it may be prudent to carefully investigate whether changes could be implemented that would not sacrifice the value of the continuous time series – for example, complementary sampling by other programs, adaptive sampling that takes into account changes in the environment, as well as increased used of automated methods where possible, and critical assessment of exactly which variables are monitored and how intensely.

The Center leadership has done an excellent job in guiding the science agenda and overcoming innumerable hurdles in maintaining surveys and research effort, prioritizing needs and leveraging resources, despite the challenges faced. There is clearly also a lot of mutual respect amongst staff, and a positive working environment. Overall the Center has impressive facilities, and is putting these to good use. There is a good mix of empirical and analytic/modeling approaches which provides a firm basis for providing scientific outputs that are grounded with real data.
The panel heard several times of future challenges in maintaining some research areas, and this suggests there is a need for strategic succession planning, as well as perhaps consideration of ways (such as dedicated mentoring) to increase the diversity of the scientific staff, particularly at the more senior levels.

Key (Specific) Findings and Recommendations (as reviewer has comments on)
(A) CCAMLR Science Issues

- **Theme 1 – Management Context and Strategic Planning**
  - Observations
  - Strengths: The SWFSC clearly plays a critical role in providing scientific advice and leadership to CCAMLR's scientific working groups. The research is well aligned with the objectives of CCAMLR. Platform for showcasing state-of-the-art research by the U.S., and leading role of the U.S. in this research area. Effective collaborations. Proven history and extensive experience
  - Challenges: Meet political obligations and need to collaborate in advancing a research agenda jointly with other nations, and through consensus.

  - Recommendations to address issue
  - Where possible, concentrate resources (staffing, operational, scientific focus) to build effectively on previous research efforts rather than expanding focus
  - Increase communication of Antarctic research, and especially field research, to the general public to increase awareness of the key role and high quality of the science
  - Vision statement is well phrased to guide motivation and focus of research, but it would also be good to see a more hypothesis-driven research agenda

- **Theme 2 – Ecosystem Data**
  - Observations
  - Strengths: Excellent long-term data collection. Transition to time and cost-saving approaches such as use of automated approaches, for example, mounted cameras to monitor crèche dates
  - Challenges: Logistically complex, expensive, time consuming, large demands on staff

- Recommendations to address issue
- Whilst recognizing the tremendous value of existing and ongoing data collection, resources and staff are clearly overstretched and it might be worth revisiting what the optimal field data collection program looks like. Unless very strong justification can be provided for undertaking surveys annually, the frequency of these could potentially be reduced to say two out of every three years. One way to assess what level of sampling frequency is necessary would be to simulation test the impact of different data availability on scientific assessments of the status and productivity of the ecosystem. There are indications that reducing slightly the number of transects in any one year may not overly impact on the accuracy and precision of survey estimates, but this needs to be explored taking into account survey variances to inform on optimal (in terms of both the quality of the data and cost-benefit considerations) numbers of transects needed, whilst bearing in mind that the overall costs and logistical challenges of conducting a survey, mean that it doesn't make sense to substantially reduce (as opposed to small changes) the number of transects (plus there are important considerations related to maintaining continuity of current time series). Where possible, attempts should be made to coordinate field sampling programs with other nations so that some data gaps can be filled through data sharing. Data collection by fishing vessels should also continue to be explored as an option for supplementing data. If possible, switch back to doing summer surveys rather than winter surveys given that this is better aligned with the research goals.
- It is critical that any time savings as a result of reductions in field time are not translated into taking on additional (new) activities, but rather into much needed time for reflection, consolidation and professional development activities of the research team.
- If time or resources are made available, it would be informative to collate climate data and projections for the region and perform analyses to determine the extent to which trends in available data might be explained by climate signals.

- **Theme 3 – Ecosystem modeling and analysis**
  - Observations
  - Strengths: Science is leading and world-class, plus supported by excellent data. Scientific efforts in this forum can provide a testbed for how to operationalize ecosystem-based management in other regions.
  - Challenges: Tactical implementation of an ecosystem-based management approach. Gaining consensus support for the adoption of a complex scientific approach that is challenging to present to a broad group of representatives at CCAMLR meetings. Feedback management approach proposed is complex scientifically and operationally (due to reliance on timely annual data collection).

  - Recommendations to address issue
  - AERDs FBM concept is scientifically sound, innovative and potentially a world leading example in implementing a tactical ecosystem-based fisheries management approach. However, the complexity of the concept and logistical challenges in ensuring and maintaining its implementation in an ongoing fashion point to the need to consider whether there are simpler approaches that might work almost as well in terms of meeting management goals related

to acceptable risks to predators. In particular, the need for an annual update is questionable and needs to be evaluated taking into consideration the value of the fishery, the risks to the predators (and, e.g., whether they are able to integrate local environmental variability over a 3-year period for example), the frequency and reliability of future data availability and longer-terms trends in climate signals as well as fishing effort. The system is highly variable and hence regular updates through a feedback management approach may well be needed, but it seems likely that similar performance could be achieved with 3-yearly updates for example (or a simpler rule). Management strategy evaluation should be used to pre-test the performance of alternative decision rules that include updating at different frequencies, as well as exploring the possibility of data not being available in some years. The robustness to climate change also needs to be explored. Given that climate change is likely a critical underlying driver of predator population dynamics, it is important to test the performance of a decision rule taking into account both short-term and long-term variability. The proposed feedback rule is an appropriate tool for use in a tactical management context, but a potential negative could be that it results in unnecessarily high variability (both up and down) in annual recommendations of spatial allocations of krill catches. Some suggestions (that could be tested using MSE) include using trends over a longer period (i.e. 2-3 years instead of intra-annual), taking the logarithm of ratios that measure an upward or downward change, explicitly considering longer-term underlying climate-driven trends so that the effect of these on population survival and breeding success is not confounded with the influence of local prey availability on predator performance). Penguins are a good choice as sentinel indicators of the health of the ecosystem (and are also early warning signal compared to some other predators), but it is also worth bearing in mind that responding closely to variability in penguin populations will result in more inter-annual variability than if the performance of other predators in the system (such as seals) is considered instead or in addition, and MSE could again be used to test the robustness of a decision rule when evaluating the performance of other predators. Fortunately the existing Foosa ecosystem model is well suited to serve as an operating model for MSE testing, especially if it can be extended to include climate drivers.

- If fishery vessels contribute to data collection for example by surveying selected transects (a subset of the full transects) in some areas, it is important to statistically analyze the data (through comparison with historic data) to determine how much loss in accuracy and precision, as well as comparability due to survey timing, is associated with doing a limited number of transects. There also needs to be some incentives or penalties to encourage regular unbiased survey efforts by industry – for example potential catch increases based on such data could be weighted based on the survey variance.
- In evaluating (via simulation and examples) the potential trade-offs arising when implementing upward and downward adjustments to the feedback rule, and hence the average reduction in krill catches that might be necessary (given conservative adjustments to account for the needs of predators), it may assist buy-in if some (simple) economic metrics are also shown. This is because the krill fishery's economic performance is relatively sensitive to catch rates (in turn a function of density).

- **Theme 4 – Incorporation into Management**
  - Observations
  - Strengths: USA is playing a leading and committed role in advancing attempts to implement ecosystem-based management in the Antarctic. Extensive experience and demonstrated success in achieving outcomes continue to underpin complex but successful international negotiations to advance the science and seek consensus on major decisions influencing the future management of the Antarctic region.
  - Challenges: Achieving consensus, geopolitics

  - Recommendations to address issue
  - The involvement and scientific input of AERD to advance efforts to establish MPAs in the Ross Sea and Antarctic regions is commendable, and largely attributable to the efforts of a very dedicated research team.
  - From a scientific perspective an ongoing focus of research efforts in the Antarctic Peninsula region that capitalizes on the long history of existing research, will firmly establish the AERD as world leaders in advancing ecosystem research and implementation in the Antarctic region.
  - Continue excellent informed dialogue with international partners but in terms of trying to seek consensus in implementing an ecosystem feedback rule, consider whether there might be easier buy-in if the method is slightly simpler, as per the recommendations above.

- **Theme 5 – Communication and Peer Review**
  - Observations
  - Strengths: High level of peer review by working groups, and strong communication expertise in negotiating with participants from member countries.
  - Challenges: Ongoing challenges in communication at all levels. The methods for spatially disaggregating the overall krill catch (e.g., feedback rule) are complex and may be difficult for all stakeholders to understand.

  - Recommendations to address issue
  - Time should be reserved to allow the scientists to increase publication of their results in the peer-reviewed literature. This should also include time for broader more strategic reflection of the science conducted to date to consolidate these findings and strengthen linkages with other research groups and findings (e.g., climate information, other predator monitoring programs). There is a challenge due to developing methods for potential implementation, but these typically need to be accepted and reviewed by the WG before they are sent for external peer-review, which limits the potential for the external review process to add significant value to the work being done. It might therefore be helpful to strengthen collaborations with other NOAA researchers to facilitate ways of seeking internal review whilst preparing and streamlining a polished version of the science for presentation at the WG meetings.
  - A simple summary of the more complex scientific analyses being presented would possibly assist greater understanding and better buy-in from the other member nations present.

- **Other**
  - Observations
    This is a small high achieving research group that are clearly very dedicated and enthusiastic. However they are clearly overstretched in terms of available resources, given also the complexity of logistical arrangements to undertake Antarctic fieldwork, long time commitments necessary for fieldwork and CCAMLR meetings, inordinate amounts of time need in international negotiations and consultation, as well as analysing data, performing analyses and writing technical reports. This has clearly left little time for professional development such as attending scientific conferences (particularly on broader topics), peer-reviewed publications, communicating and interacting with colleagues, as well as time to step back and reflect on the science as a whole. The latter is important to capitalize on the wealth of information and science conducted to date, as well as ensure that there are opportunities for a broader strategic overview of the science and facilitation of linkages with other areas.

  - Recommendations to address issue
  - The scientists should be commended for doing an excellent job, but at the same time it would be good to reprioritize their work plan to allow some time for consolidating research and professional development. If reprioritization of resources means that field-based sampling duration and frequency needs to be reduced, this is likely to be of considerable concern to scientists who have invested tremendous time and energy in collecting long continuous time series, and hence the reasons for this need to be clearly communicated, together with the scientific justification, such as via analyses that quantify the trade-offs between reduced sampling and loss of accuracy and precision in terms of using the data to understand past changes in the ecosystem and to make future projections.

(B) Regional Office Ecosystem Science

- **Theme 1 – Management Context and Strategic Planning**
  - Observations
  - Strengths: The SWFSC has responsibility for providing scientific advice for a broad range of fish (including salmon), marine mammals, turtles and invertebrates, and is also at the center of one of the longest running monitoring programs (CalCOFI) and hence represents a hotspot of information describing all levels of the ecosystem – this provides an almost unique opportunity to advance rigorous ecosystem science that is firmly validated using empirical data, and can be tested in a highly dynamic climate-driven ecosystem.
  - Challenges: The Anthropocene epoch has arrived, in which the Earth's systems are driven largely by the impact of human activities, and there is a challenge for the science to keep pace and broaden its focus from a more narrow physical-biological focus to one that explicitly accounts for anthropogenic climate change impacts (as an additional layer on top of climate variability), as well as incorporating human uses, societal values, socio-economics (the focus of the next review so not elaborated in detail here), and dynamic interactions and feedback from human users.

- Recommendations to address issue
- The Center is to be commended for its role in contributing to the Fishery Ecosystem Plan development as well as the CCIEA and WRAP, all of which considerably advance the strategic framework guiding the development and integration of ecosystem science into the future
- Moving to tangible implementation of ecosystem approaches is a journey and this has started along the right road, but progress could be catalyzed by putting together the pieces from individual research and sampling programs to better synthesize and explore the interacting components and relationships. In order to guide future research efforts and initiatives, there also needs to be clearer direction as to the extent to which the science is intended to benefit both the ecosystem and the human end users. For example, much of the current focus is on sustainable management or protection of individual species, as well as ways in which these species (and the sampling that is needed to monitor the populations) are influenced by climate variability, with less of a focus on how research findings could be used to improve the economic efficiency of, and reduce impacts by, the human users, noting that this can in turn have significant positive feedbacks, such as demonstrated by the examples on using dynamic ocean management approaches. The current research is appropriately aligned with mandates to manage and protect a range of species, and these initiatives collectively contribute to advancing ecosystem science. However, in order to achieve a more holistic ecosystem approach that aims to overview and manage the system as a whole, there needs to be a concerted effort to provide the resources and motivation for taking the extra step of pulling all the pieces under a unifying umbrella. The WRAP has the potential to serve this function.

- **Theme 2 – Ecosystem Data**
  - Observations
  - Strengths: The scale, extent and quality of ecosystem data collected is phenomenal and the Center has developed excellent services (ERDDAP is an excellent advance) for sharing the data. Automation of data processing and plotting for incorporation into status reports is commendable. The CalCOFI book is a great example of consolidation of research outputs.
  - Challenges: Data collection is both costly and time-consuming, and individual data collection programs that have been designed historically for other purposes are not always as well aligned as would be ideal to answer a new set of ecosystem science questions (i.e. measurements of physical variables and full foodweb variables from the same times and locations). The sheer volume and diversity of the data that is collected can make it overwhelming and confusing for managers and stakeholders.

  - Recommendations to address issue
  - The ecosystem data collection activities are vital and should be supported and continued into the future, but given limited resources as well as a dynamically changing environment that is being monitored, it would be advisable to bring a small group of relevant experts together to critically assess what is currently being done, whether there are synergies that could be better leveraged, whether it is possible to reduce the scale of sampling, or to drop or automate monitoring of any variables, as well as better align with

other relevant data collection programs to enhance utility of the data in informing ecosystem approaches. Adaptive sampling methods show great promise provided care is taken to ensure that the comparability of valuable time series is not compromised. Modeling approaches could be used to assist in informing on optimal (given resource limitation constraints) sampling programs to achieve pre-specified goals. The development and implementation of methods such as Environmental DNA should be encouraged.
    - The dynamic updating of the CalCOFI state of the CA current report is an important advance. The suggested next step is to generate a very short high level summary, using plain language that could be used as a broader communication tool, and importantly as a rapid succinct update for key stakeholders, managers and policy makers.

- **Theme 3 – Ecosystem modeling and analysis**
    - Observations
    - Strengths: The Center has strong partnerships that can support development of ecosystem modeling and analyses. There are a range of existing models that can be used to improve mechanistic understanding of physical processes. There is an Atlantis model of the California Current system. The dynamic ocean management shows promise as a tool for forecasting risk and optimizing activities.
    - Challenges: The future uptake and responsibility for hosting dynamic ocean forecasting outputs is unclear. The HMS modeling has made important advances in linking albacore distribution to physical habitat variables but further work is needed to strengthen the relationship, for example by incorporating primary production relationships. The nonlinear time series analyses are interesting and show some potential, but need to be tested and validated using real examples, including nonstationary climate change impacting on a fishery for example.

    - Recommendations to address issue
    - My overwhelming impression is that there is a paucity of appropriate coupled physical-biological models of the California Current, at the correct scale, and with the correct degree of resolution to address relevant questions for the region, and hence provide an integrated and relatively rigorous foundation to support climate-smart ecosystem decision making. My main recommendation is thus to create an ecosystem modeler/s position to focus on developing one or more coupled physical-biological models of the system, preferably at the regional scale (regional downscaling should be a priority), and incorporating higher trophic level predators also. Given the key role of forage fish species in the California Current system, as well as their sensitivity to environmental variability, and global efforts to improve management of forage fish to achieve ecosystem management goals, the model should include this group. Moreover, any model developed should draw on the wealth of available data to inform and validate the model, and for use in informing future projections under a range of climate change scenarios. Ideally the model should be designed so that it could also be used as an operating model in a management strategy evaluation context.

- **Theme 4 – Incorporation into Management**
  - Observations
    Strengths: Several mechanisms have effectively been put into place to facilitate the translation of ecosystem considerations into management decision making – for example, the FEP. The new forage fish ruling is an important example of use of the framework for incorporating ecosystem considerations into management. Clear guidance as to the current acceptable uses of the CC Atlantis model is another important development.
    Challenges: Significant challenges remain, but these are not unique to the Center as globally the research and management community are grappling with these issues – the SWFSC is fairly uniquely positioned to take a leading role in advancing the incorporation of ecosystem considerations into the management arena (for reasons mentioned in the text above). To achieve these aims, development of further modeling and analysis tools are needed. There is also a need to substantially advance associated economic and social science considerations (not discussed further here)

  - Recommendations to address issue
  - Greater synthesis and integration of existing research is a necessary first step, and there is a clear need for an ecosystem modeler to further consolidate and quantify key relationships and mechanisms driving the system, as a platform for informing decision making.

- **Theme 5 – Communication and Peer Review**
  - Observations
  - Strengths: Commendable outputs and communication initiatives across all areas. Strong collaborations with a broad range of partners. Ongoing improvements in web-based communication.
  - Challenges: Need to fully capitalize on the great work that has been achieved by increasing publication in peer reviewed journals. Need to simplify presentation of complex detailed reports.

  - Recommendations to address issue
  - The Center's scientific staff are performing well, but do not seem to have sufficient time allocated (or a high enough priority accorded) to publish as much as they could in peer reviewed journals. I recommend according higher priority to the professional development of lead and other scientists, and encouraging publication; recognizing that this may not be achievable unless other tasks can be reduced (such as via examples provided). In particular, it would be good to focus on some high impact publications that present integrated overviews of the CC system. At the same time, it is important that long time series data be adequately described and recorded.
- **Other**
  - Observations
  - Recommendations to address issue – as for AERD

Conclusions
The Review panel were all impressed with the high quality of the ecosystem science program, the Center leadership and staff, as well as the dedication and enthusiasm in managing large and complex workloads, long-term field programs and international negotiations. Some suggestions have been provided to maintain these strengths as well

as adapt to future challenges ahead. A key challenge that emerged was the need to consolidate existing research and reassess how to best go forward with declining resources, particularly for fieldwork. A second clear theme was the need to improve integration between different research areas, and develop an integrated overview of the structure and functioning of the CCLME that draws on the considerable data and scientific understanding to date. Lastly, the ecosystem science program could benefit substantially if one or more ecosystem modelers could be brought on board to assist in synthesizing ecosystem science and developing relevant ecosystem models to support efforts in advancing ecosystem based management approaches.

Reviewer 3 - Report on Program Review of Ecosystem Science
Science Center: Southwest Fisheries Science Center
Address: 8901 La Jolla Shores Drive, La Jolla, CA 92037-1508
Dates: 18-20 April

Background
The panel was asked to evaluate the programs at the SWFSC with respect to Ecosystem Science. While the idea of Ecosystem Science and its derivative of Ecosystem Based Fisheries Management (EBFM) have been the topic of discussion for some time, the actual implementation of EBFM has been rather slow to develop. However, after three intense days of presentations, I am confident that EBFM has a future and that various aspects of EBFM are already in place. The overall quality of the presentations and science carried out was excellent with a surprising number of time series that span many decades. While many pieces of the puzzle have yet to be put into place, the quality and quantity of data that are now available that can be put into the context of the marine environment is outstanding and will provide the basis for analysis that will provide critical insight into how species and ecosystems will respond to climate change.

The programs reviewed fell into two distinct geographic regions the Southern Ocean (Antarctica) and the California Current LME. Research in Antarctica is carried out completely within one division, the Antarctic Ecosystem Research Division (AERD), while research in the California Current LME is carried out across multiple labs, Divisions and Centers. Research carried out by AERD was the first to be reviewed by the panel followed by the California Current. This created an interesting contrast for the panel in that the AERD is a single research Division that included broad expertise designed around Ecosystem Management. Whereas, research within the California Current appeared to be set up with an initial focus on stock assessment and single species management that has over time embraced and pivoted towards EBM. AERD also differed in that its main drivers or “customer” is CCAMLR an international commission set up under the Antarctic Treaty with the primary US based “customer” being the State Department. CCAMLR included EBM from its inception and proposed the concept of using predators as ecosystem sentinels. Whereas, the “customers” for research output from the California Current are the Pacific Fisheries Management Council and the NMFS Regional Offices. As a consequence research carried out in the Antarctic appeared to be more cohesive and integrated, which is not surprising given that the AERD is a single division with a more unified structure and a more focused mission. Given these differences I will provide comments separately for the AMLR program and the California Current.

A major concern across both programs is the lack of resources and that they are being asked to do more with less. While it is easy to make recommendations of what should be done or could be done it is hard to suggest how to achieve many of these recommendations at a time when resources are limited or in fact declining. Many of the programs are fully committed to just sustain the measurements they are currently mandated to obtain. While we think a way forward is to greater collaboration across divisions and centers, we also acknowledge that collaborations are not free and that they take time and resources
(travel) to maintain.

General Observations and Recommendation

AERD- As mentioned above EBM was incorporated into the research carried out by the AERD from the beginning. The response of top predators to changes in their prey and to the environment was well integrated into the research. CCAMLR has been a leader in the development of and implementation of EBFM. They are also in the unique position of being able to initiate a management regime prior to the development of a fishery and thus avoid many of the problems associated with placing new restrictions or management policies on an existing fishery, which is the more typical fishery management approach.

In his presentation Johnathan Kelsey of the U.S. Dept. of State commented that the principle goals of the US AMLR program was to provide direct scientific input into the CCAMLR consultative process and to show USA leadership within the Antarctic and the greater Scientific Community. To this end I sought input from a number of colleagues in the United Kingdom and Australian Antarctic research programs. The response I received was resoundingly positive in terms of the perception of the quality, importance and relevance of science carried out by AERD. Across the board individuals commented that the AERD's input to CCAMLR was critical. A common concern was that AERD has been critically hampered with respect to resources in terms of both personnel and support for logistics and science. Over the course of the program they have had to cut ship time and more recently have moved from a summer cruise to a winter cruise. Similarly land based predators studies have been severely curtailed and or restricted. It is important to note that while AMLR inherited the amazing 30 yr. time series on seabirds from the Copa Field Station on King George Island that had been previously supported by NSF, they also inherited the logistical responsibilities and maintenance costs associated with keeping this field station operational.

Key (Specific) Findings and Recommendations (as reviewer has comments on)

- **Theme 1 – Management Context and Strategic Planning**
    - Observations- Strategic planning within the AERD-AMLR program appears to have two major goals. The first is to develop an operational EBMF approach that regulates krill harvest by monitoring the foraging behavior and demographics of key predators like seabirds and pinnipeds. They have developed an EBFM program that at least on paper could be implemented in the real world. While I was impressed with the level of sophistication, some members of the panel thought that it was too complicated to become operational. While I understand this concern, they have significantly advanced the conceptual framework and potential implementation of EBFM for krill. The approaches developed here can be applied to other systems. Further, if any EBFM program has a possibility of implementation it will be within CCAMLR.

    - The second major strategic goal is to develop a process of establishing MPAs in the Southern Ocean. MPAs are important in two ways, first many stakeholders want to create MPAs to preserve and protect components of Antarctica. They can also serve as no take regions that can be used as controls to test the efficacy of EBFM. There was some discussion within the panel about the amount of effort that AERD has put into the development of the Ross Sea MPA, as AERD has never had a presence or collected any data here. This came up not because there were concerns about the quality of the work, but more about given the

limited resources available within AERD whether this was sustainable. It was clear that the AERD program is playing a significant and critical leadership role in the Ross Sea MPA. Further, Johnathan Kelsey from the State Department further clarified the critical role that AERD plays in helping to direct the formulation of policies regarding MPA development. For example, the USA has a significant presence and interests in the Ross Sea, probably more than any other region as McMurdo Station and the air bridge are operating through this region. Many NGOs and other stakeholders associated with the Ross Sea are based in the USA and have made the Ross Sea their highest priority. The Ross Sea is the first MPA under discussion and thus it requires attention by the USA. The Department of State sees AERD as the appropriate USA representative for developing the science behind Antarctic MPAs. These are being developed within CCAMLR and AERD is the primary conduit for USA science to CCAMLR. No other RFMO has taken on MPAs to the level that CCAMLR has. AERD has taken on a leadership role in the development of MPAs in the Southern Ocean that will have global implications. Precedents agreed upon for MPAs in CCAMLR will help develop MPAs in other regions of the world, so it is important for the USA to play a leadership role here and AERD is the appropriate agency to do this. Finally, George Waters and AERD team has the expertise to address this issue and AERD is therefore in an excellent position to lead this effort. However, it might be worth considering whether additional resources can be provided to AERD to accomplish this rather new and increasingly time consuming task.

- There appeared to be limited interaction between the AERD and the NSF LTER. While both organizations know about the other, there is tremendous opportunity to share data and resources as they are collecting data along the Antarctic Peninsula. AERD is focusing on the northern limit while the LTER the adjoining southern component. Together they provide input on a large contiguous region.
- While there has been significant interaction between the AERD and the NSF Polar Programs in the past, this appears to be less so at present. I suspect that this may due to the fact that Polar Biology and Medicine is now managed by a program manager who rotates every 2 years. This prevents the development of a long term vision by NSF as well as making it difficult to develop and sustain connections with other programs like AERD. This is the only program that is managed within NSF Polar Programs that is a rotating position. In the recent past this was a permanent position. Relevant to AERD is a permanent program manager at NSF would foster better coordination and collaboration between NSF basic science research PIs, the NSF LTER and AERD.

- **Theme 2 – Ecosystem Data**
  - AERD has been collecting oceanographic data with coupled predator measurements spanning several decades. These data are unequalled from any other region. Unfortunately due to a reduction in resources (ship time) and logistics they have had to move to a shorter winter survey. Plans are in place to go back to a summer survey operating 2 out of every 3 years.

- While this is a reasonable suggestion, they need to look at their existing time series to see if such a sampling scheme would capture the known variability in krill recruitment and predator foraging patterns and behavior.
- AERD could play an important role in the Southern Ocean Observing System (SOOS). SOOS is just starting to develop implementation plans for various regions in Antarctica. AERD is well poised to play an important role in the development of the SOOS effort in the WAP. Further, interaction within the SOOS program might provide further support for the sustained collection of both oceanographic, krill and predator data.

- **Theme 3 – Ecosystem modeling and analysis**
  - While the observations are extensive it appears that the analysis of these data has only been recently received significant effort. This is in part due to personnel being stretched to the limit occupying the field sites, being at sea and attending the various CCAMLR meetings.
  - There is great potential for analysis of the existing time series within the context of climate change. Such an effort could benefit from inclusion of LTER data and personnel and individuals from ERD.
  - Funding of some quantitative post docs could help to get these data out. The addition of a few new personnel has already significantly increased the programs productivity.
  - While AERD is a well-integrated program that works well within their own group, there is the appearance that they work in isolation and could take advantage of the expertise of individuals within the SWFSC and other centers like AFSC. The top predator group could benefit from interactions with top-predator researchers at the AFSC.
  - There is a great potential for comparative analysis across habitats. For example Antarctic and northern fur seals have equivalent life history patterns and yet populations of Antarctic fur seals are or have been increasing while Northern fur seal populations are in decline.

- **Theme 4 – Incorporation into Management**
- The AERD program is well suited to move their observations in the CCAMLR management scheme. See earlier discussion points.

  - The Dept. of State is getting good information from AERD that is being used in the CCAMLR process. More resources would provide more data that would be used and allow an expansion of US involvement in CCAMLR. This would allow the USA to take on a larger leadership role. Given the limited resources currently available they have to make strategic decisions on what things to do and not do. There is room for more capacity and more resources would allow them to take on a larger role.

- **Theme 5 – Communication and Peer Review**
  - The science is well communicated within the CCAMLR program. AERD has also been involved in other outreach efforts.

Conclusions

The AERD program needs to work out a way of maintaining a summer field program for both the predator observations and the ship based surveys. These are the only predator prey and oceanographic data that are collected in the Southern Ocean that are appropriately matched in time and space. The AERD program is held in high regard by CCAMLR and the international Antarctic research community. Resources need to be made available to allow AERD staff to focus on data analysis and interactions within NOAA and to the larger scientific community (NSF, LTER and academics). Some resources might become acquired by working closely with academic partners both in the field and in the analysis of data. While development of EBFM approaches are important, AERD might consider increasing their focus on bio-geochemical coupling to develop proxies to predict krill recruitment. While the role of climate change is implicit it was not clear how much of climate change research is included in their current research. I suspect there was a lot of climate change related work that they did not have time to report on in this review.

Participation in joint NSF-NOAA programs like GLOBEC and CAMEO should be encouraged. These programs provided resources to jointly fund NMFS scientists who worked with NSF funded Academics. These programs have provided mechanistic insights in climate forcing throughout the food web (GLOBEC) or comparisons across habitat types or ecosystems. Such a jointly funded program would be effective throughout the various research programs we reviewed. Development of such a joint effort require would significant input and vision from upper level management within NOAA-NMFS and NSF.

California Current LME

General Observations and Recommendation. The ongoing research into the California Current is impressive and extensive. Some of the longest time series in biological oceanography have been collected by the CalCOFI program. There are also a number of quite impressive time series on California sea lions, ground fish, sardine and anchovies and salmon. As mentioned earlier the AMLR program was seen as a small but well integrated program that is probably related to it being housed in a single division. In contrast the Cal Current LME crosses many divisions and even across centers. While many different data sets were presented many of these data were presented in isolation. This is a major shortcoming that could be remedied with a little cross pollination between programs and divisions that would facilitate integration and synthesis of these diverse data sets. A good example of this is where the ground fish surveys incorporated some of the top predator data and the ERD climate predictions that incorporated seabird and marine mammal data. However, a surprising amount of data used in the ERD analysis were collected by investigators outside of NOAA. While this is not a problem, there are some outstanding data collected by NMFS researchers within the Cal Current that could also be incorporated into these synthesis efforts.

Key (Specific) Findings and Recommendations (as reviewer has comments on)

- **Theme 1 – Management Context and Strategic Planning**
    - The NMFS regional offices and the Fishery Council seemed to be quite pleased with the products and interaction they have with investigators from the SWFSC. The one concern is that appeared to be little cross divisional coordination and planning.

- There is tremendous potential to share resources and capabilities across Centers and Divisions. Synthesis across habitats and species should be encouraged.
- While climate change was a theme for some components of the Ca Cur LME it was missing in some presentations, even though the data were available to relate the observations to climate driven processes.

- **Theme 2 – Ecosystem Data**
  - Given the history of this program a lot of data were collected on single species as part of stock assessments. However, NMFS investigators have made significant progress in starting to consider these data in the context of environment parameters and with respect to other species.
  - More effort should be put into collecting data with appropriate environmental correlates and with respect to other species (predator/prey)
  - The US IOOS (Integrated Ocean Observing System) is in the first phase of its development and has yet to be fully implemented. From its initiation it was clear that IOOS could not support all of the various components of observation that are needed and that it would have to rely on within agency and cross agency input and coordination. Further, at an international level GOOS and SOOS have been trying to determine what components are necessary to develop the biological components of an ocean observatory. Many of the measurements that are currently carried out on a routine basis within the California Current provide both insight as to what measurements are key, but could also provide data and time series that can and should be incorporated in IOOS. This would not only be helpful to IOOS, but it would help support the need for sustaining these time series.
  - A component of IOOS that is under development is the Animal Tracking Network or ATN. There are is an internal NMFS report and a publication on the importance of a nationally funded program. Such a network would provide important information that would be immediately incorporated into EBFM. Throughout the 3 days of presentation there were many examples of the value of animal tracking to understand the distribution and movement patterns of many species. The ATN needs the support of the Centers.
  - As I mentioned in the AERD section, AERD could benefit from further interactions with other NMFS investigators. This is particularly relevant for the upper trophic level investigators. A significant international effort went into the development and implementation of CEMP (CCAMLR Ecosystem Monitoring Program). Many of the approaches developed within CEMP could be transferred to the California Current. Finally there are very few upper trophic level researchers at the SWFSC and they would benefit from interactions with other upper trophic level investigators within the two centers.
  - The pinniped data (specifically California sea lions) is a spectacular data set and time series. This is the only example of a time series where the diet, demography and to a limited extent the movement patterns of a marine mammal population that has recovered from earlier exploitation. The CSL demographic data set is the first example where the mandate of the Marine Mammal Protection Act of 1972 has been achieved. This is

the example of a population where the parameters set out in the MMPA (OSP, OSY, K) have been able to be quantified. Further, the Calif sea lion is the only sea lion out of 6 species that has been increasing and recovered. From a management perspective such data can provide critical insights to understand why these other populations are in decline. Most notable in this context is the Steller sea lion, which is an ESA listed species.
    - All of the sea lion investigators commented that resources have limited their ability to complete their measurements or have curtailed data analysis. In some cases they mentioned the high cost some key measurements. However, cost is relative. Most of these sea lion efforts are colony based and as such have relatively low logistic costs. In comparison to many of the classic fisheries stock assessments where ship time is critical these efforts are relatively inexpensive. This is true even considering the cost of satellite tracking, which to most predator researchers are the most expensive thing we do.

- **Theme 3 – Ecosystem modeling and analysis**
    - I don't recall seeing a single food web description of the California current in any presentation. Again a problem is that many of the data while impressive were often collected in isolation.
    - A food web with energy flow and or some indication of interaction strengths would go a long way in developing hypothesis about how the Calif Current works. It would also help to focus the research on important components of the ecosystem
    - Development of food webs and or models of energy and or nutrient flow would be quite instructive.
    - ERD has shown a significant capability to integrative and correlate animal times series data into an environmental context. This was seen a real strength within the Center. Further, collaboration of this group with other investigators within the two centers should be encouraged and strengthened.
    - During the course of our discussions we have suggested that comparative analysis could be quite informative. One of the ERD presentations made comparisons between all four Eastern Boundary Current systems, which provided some interesting results.

- **Theme 4 – Incorporation into Management**
    - The regional NMFS offices were quite supportive of the data supplied by the SWFSC as was the Fishery Council.

- **Theme 5 – Communication and Peer Review**
    - The science being collected within this program is outstanding. However, many of the time series presented have not been published. This is a major concern as some of the data were collected by individuals who are nearing retirement.
- **Other**
    - Recommendations to address issue

Conclusions

The research being carried out in the California Current Ecosystem is quite impressive and has many examples of EBM and EBFM. However, while the program is impressive and producing some amazing data it has yet to reach its full potential. The most significant issues are collaboration between groups and the development of some larger big picture hypothesis that could help to better integrate research across the various division. This is a challenge due to the number of investigators and their wide geographic distribution (like HMS). Some efforts to bring the various groups together for discussions and synthesis might prove useful here. Another common thread is the lack of resources, for some groups this was truly hampering their abilities, while others were able to get outside support to expand their efforts. An ancillary component of this lack of resources is the impending retirement of a number of key dedicated researchers. As a number of these investigators were the key players in the development and acquisition of some significant and important time series, it is critical that these time series be completed documented and fully archived before they retire. It would be ideal if these time series were published before these individuals retire. This is important so that they get the credit they deserve for sustaining these data for such a long time, but also because they are the ones who know the data best. Bringing on some young quantitative field savvy post docs would not only expedite the analysis and subsequent publication of these time series, but would also provide a conduit to train and retain the next generation of NMFS researchers. There is another angle on the impending retirements that is it provides the ability to bring into NMFS a new cohort of individuals who have be trained with the newest tools and techniques. So this should be seen as an opportunity.

Reviewer 4 - Report on the SWFSC Ecosystem Science Research
Science Center SWFSC
Dates April 18-20, 2016

Review of Antarctic Division
General Observations and Recommendation

1. The survey design and data collection going forward may benefit from a retrospective analysis of past data to insure future field and ship survey data collection is efficient and statistically rigorous especially in light of the need to reduce effort.
2. The krill harvest feedback model is an innovative ecosystem approach to fisheries management but it is also complicated, sampling intensive, and possibly producing highly variable annual adjustments. It may be the best approach but some management strategy evaluations to evaluate its robustness to climate change and performance relative to other precautionary approaches are merited.
3. If the program moves to a break in some field work as envisioned during the 2 year on and 1 year off ship schedule, there could be an opportunity to conduct retrospective analysis and a series of publications to both review sampling design and communication more broadly with the scientific community.

Key (Specific) Findings and Recommendations (as reviewer has comments on)

- **Theme 1 – Management Context and Strategic Planning**
    - Observations: The US Antarctic Program lead by the US Dept. of State and the Convention on Conservation of Antarctic Living Resources (CCLMR) have identified specific management needs that include need for scientific advice in management of Krill and toothfish fisheries and advice to develop large marine protected areas (MPAs). The SWFSC Antarctic Ecosystem Research Division (AERD) is the NOAA research program tasked with supporting the US and Convention needs. In particular, AERD is focused on providing the science in support of krill fisheries management and MPA development.
    - Recommendations to address issue: The Division has clear goals and direction which are focused on addressing the science needs in support of krill management and development of MPAs. Their approach involves a mix of field work (ship time and field stations) as well as data analysis and modeling. A trajectory of declining ship and field station days over the years raises concerns about how their field program which is an integral part of the research program will be maintained. It was noted that some years ago they had 105 days at sea and now due to budget constraints they are planning on 25 days at sea and discussing moving to a schedule of skipping ship work one year in three. On the bright side during a year without field work there is an opportunity to analyze data and write papers.

- **Theme 2 – Ecosystem Data**
    - Observations: The Division collects a diverse suite of ecosystem data from acoustic surveys (krill biomass) and penguin and seal population demographics from field station surveys. Some of these time series extend back 25-30 providing a critical temporal perspective. Data has been collected during both winter and summer periods and in some instances they collect observations on predators and prey simultaneously

in space and time to achieve an important realization of predator-prey dynamics. Oceanographic data is also collected but it wasn't clear how much these data were used. Commercial krill fishing data is also used in their assessment work.

- Recommendations to address issue: The Division maintains an important series of ecosystem data that support their krill assessment work, some of their MPA development work, and provides critical information on the spatial and temporal dynamics of a portion of the Antarctic marine ecosystem. The survey design and data collection going forward may benefit from a retrospective analysis of past data to insure future field and ship survey data collection is efficient and statistically rigorous especially in light of the need to reduce effort.

- **Theme 3 – Ecosystem modeling and analysis**
  - Observations: Much of the program is focused on the development of the krill feedback model. This a very creative and innovation approach that takes a statistical krill stock assessment model adds spatial resolution, incorporates ecosystem indices through penguin reproductive condition, and then adjusts the krill fishery harvest adaptively with feedback from predators and krill acoustic surveys. The MPA development work involves assembling and mapping ecosystem data, outreach with stakeholders to identify objectives to be incorporated into the MPAs, and working with international partners to develop the details of the MPAs that will achieve CCMLR consensus.

  - Recommendations to address issue: The model/approach is innovative, it uses multiple data sets, it's adaptive, responding to changing conditions, incorporates ecosystem indices, and produces tactical advice. It represents the leading edge of an ecosystem approach to fisheries management. However, it is a complicated approach requiring considerable field and analytical work to maintain and potentially producing highly temporally dynamic quotas. It might be worth considering a more phased in approach such as using the ecosystem indices as separate indicators in conjunction with a krill assessment model with a decision rule to adjust the krill harvest based on moving average of the ecosystem indicators. There's no doubt in the value of monitoring and using ecosystem indicators is important, it's just how they are used, whether they are hardwired into the model or linked in other ways. In any case conducting management strategy evaluations to compare the benefits and performance of this approach (model) relative to other precautionary approaches would be an important step going forward. The Antarctic is projected to experience significant impacts from climate change, warming, loss of sea ice, ocean acidification, etc. Yet there was little discussion of how the ecosystem may change spatially, structurally, and functionally by the 2050's in response to climate change that might provide a strategic context for research and management. Is the krill feedback model and associated sampling robust to changing climate that may alter krill growth/mortality, spatial distribution, etc.? Lastly there was a brief mention of the use of a spatial ecosystem model but it seemed that due to personnel constraints that this tool was not developed and used as fully as it could to benefit the program. A fully time

ecosystem modeler would be an important asset to the Division.

- **Theme 4 – Incorporation into Management**
  - Observations: The work of the Division directly supports the needs of US ALMR and CCLMR specifically on krill fisheries management and MPA development. Division staff participate in CCLMR meetings and submit their research to working groups and in scientific reports.
  - Recommendations to address issue: The work of the Division is routinely incorporated into the CCLMR and US AMLR process supporting management.|

- **Theme 5 – Communication and Peer Review**
  - Observations: The work of the Division is communicated via CCLMR working groups and papers as well as peer-reviewed journal publications.
  - Recommendations to address issue: The schedule and demands of CCLMR appear to leave little time for staff to communicate the scientific results of the Division to the broader ecosystem community outside of CCLMR via conferences and peer-reviewed publications. The Division is developing an innovative and cutting edge ecosystem approach to fishing and maintaining a suite of valuable ecosystem time series. A break in field work as envisioned during the 2 year on and 1 year off ship schedule could be an opportunity to conduct retrospective analysis and a series of publications to both review sampling design and communication more broadly with the scientific community.
- **Other**
  - Observations: This is very unique program that maintains a significant field component with very challenging logistics, heavy time and report demands from CCLMR, while maintaining a long term ecosystem survey and advancing an approach to ecosystem management through a harvest model and MPA development. The achievement of this Division are impressive.

Review of California Current Ecosystem (CCE)
General Observations and Recommendation

1. The strong support of the Center's work by the Region and Council is very impressive and Center staff are to be commended for addressing management's needs and building and maintaining a strong relationship with managers.
2. An overarching strategy and objectives for ecosystem science research was not articulated in the review. Ecosystem work is done in each of the Divisions but based on many of the presentations integration and coordination could be improved. A Center-wide ecosystem strategy with Division-specific objectives would help strengthen and coordinate ecosystem research.
3. The Center maintains a number of long term survey and sampling programs. As it becomes more challenging to maintain all these efforts, it is timely to conduct a review of all the cruises and data collection programs to look for ways to develop a more integrated and efficient ecosystem survey program.
4. The Center has a strong research program assessing the role of bottom-up (upwelling) in the ecosystem but research on food web dynamics and uses of ecosystem models were not well highlighted in the review talks. It is important that this component of ecosystem research receive considerable attention and

take advantage of ecosystem models. A full time ecosystem modeler position would be an important contribution to this effort.

5. The annual California Current State of the Ecosystem Report and shorter IEA version are excellent products that combine a suite of near-real time indicators that contribute to the Council's annual report and communicate to colleagues and the public. Efforts to streamline and automatic this effort where possible should be pursued.
6. The Center's WRAP reflects a coordinated effort across the region and presents a comprehensive approach to climate work in the region and a valuable tool for Center research planning. The species vulnerability to climate change will be an important contribution to this work. Overall the Center is on track to address climate-informed management.

Key (Specific) Findings and Recommendations (as reviewer has comments on)

- **Theme 1 – Management Context and Strategic Planning**
    - Observations: The Regional Office (Turner) noted the region had 120 species, 4 management plans, ESA needs for salmon, and 4 sea turtles and 30 mammals with MMPA needs. Six Regional priorities were identified as: i) continued support for Fisheries Ecosystem Plans (FEPs), ii) support with the forage fish amendment, iii) information on climate impacts on the ecosystem, iv) information to support reduction of interactions with protected species, v) information to support reduction in inland climate impacts on salmon, vi) information on causes of pinniped unusual mortality event. The Regional Office noted that they have a very close relationship with staff form the SWFSC and receive excellent support. 4 SWFSC staff are on FEP plan teams and SSC.
      A presentation from the Pacific Fisheries Management Council (Dahl) identified work and products from the Center including the California Current report that provides an ecosystem context for the single species assessments, work on the forage species amendment, the development and review of the Atlantis Model used to evaluate harvest policy, work on ecosystem effects in sablefish stock assessment, and development of ecosystem indicators. The Center is responsive to Council needs and communication between the two functions well.

      While the Center is doing well at addressing the needs of managers, an overarching strategy and objectives for ecosystem science research was not articulated in the review. Ecosystem work is done in each of the Divisions but based on many of the presentations integration and coordination could be improved. A Center-wide ecosystem strategy together with Division-specific objectives would help strengthen and coordinate ecosystem research.

    - Recommendations to address issue: The strong support of the Center by the Region and Council is very impressive and SWFSC staff are to be commended for addressing management's needs and building and maintaining a strong relationship. While the Region or Council didn't specifically request that the Center take more of an ecosystem approach, their priority on information on climate impacts and forage fish will require an ecosystem approach. An overarching strategy and objectives for ecosystem science research was not articulated in the review. Ecosystem

work is done in each of the Divisions but based on many of the presentations integration and coordination could be improved. A Center-wide ecosystem strategy with Division-specific objectives would help strengthen and coordinate ecosystem research.

- **Theme 2 – Ecosystem Data**
  - Observations: The Center collects data on many components of the ecosystem with a number of different surveys including CalCOFI, coastal pelagics, demersal fishes, pelagic juvenile rockfishes, salmon, pinnipeds, etc. Many time series and surveys go back many decades with the 65yr-long CalCOFI being the longest. For example, the 34-year long pelagic juvenile rockfish survey, coast-wide since 2011, provides a snapshot of the pelagic ecosystem and data for key ecosystem indicators. Many presenters noted the difficulty in maintaining staffing and funding for these various surveys. Some exploratory genomics work was also presented as a possible tool to help with species identification especially in the CalCOFI larval data. The Environmental Research Division's Data Access Program (ERDDAP) software has emerged as a very valuable tool in maintaining and serving much of the ecosystem data, especially the environmental data and is being adapted by many other institutions. Data on ERDDAP are PARR compliant.
  - Recommendations to address issue: The Center's surveys provide valuable long term data on various components of the ecosystem. However, many were started to address species specific questions and over time changed in spatial and temporal coverage and species sampled. Given budget and staffing issues and an ecosystem focus, it would be timely to conduct a review of all the cruises and data collection programs to look for ways to develop a more integrated and efficient ecosystem survey program, including sampling, processing, and timely data analysis, that also continues to address as needed the species-specific needs. Some statistical sampling design work could help this effort. The current evaluation of the role genomics can play is a nice example of looking to new technology. The use of dynamic habitat models in survey design is another example of an innovative approach.

- **Theme 3 – Ecosystem modeling and analysis**
  - Observations The presentations were largely focused on single species analyses or links between population parameters and the environment. A diverse set of time series covering a range of species from many locations have been collected in many instances covering decades. There are two broad aspect of ecosystem dynamics, bottom-up and top-down. There was considerable discussion of the physical system (upwelling dynamics), its spatial and temporal dynamics, impacts on biology including some high trophic species, its nonlinear aspects, use of circulation models to model it, and projections of how this will change in response to climate change, etc. This is very important work given the dynamics of the system and folks at the Center are doing excellent work in this aspect. However, a consideration of an integrated food web perspective of the CC was largely lacking. There was no presentation of the CC energy flow or food web model (Ecopath Model or similar) from plankton to apex species and including various fishery removals. Perhaps

the lack of a food web perspective was just an oversight or is something everyone already understands but it suggests the possibility of insufficient focus on thinking about the CC in a trophic/energy flow perspective. This is a perspective that would help develop and direct CC ecosystem research and perspective that is especially key to issue of management of forage fish in the ecosystem and assessment of climate impacts. An Atlantis Model with full spatial and trophic resolution has been built in collaboration with the NWFSC but apart from a brief mention, it or any application of it was not in evidence in the program review. It would seem that the process of building this model and running it would be used to identify current strengths and weaknesses in the Center's ecosystem surveys and provide a context for our current understanding of the energy flow in the CC and questions for future research. By contrast, the Center's salmon work both inland and oceanic appears to have done an excellent job in integrating processes, observations, and models. Habitat models using environmental data in generalized additive models (GAMs) are widely used across the Center for applications ranging from demersal fishes to highly migratory species. Habitat models also serve as the basis for work to produce near-real time spatial maps for whales and bycatch species with the goal of employing dynamic ocean management to reduce various types of interactions with these species. Engaging users in feedback of the effectiveness of these products should lead to advances of this approach.

- Recommendations to address issue: There is an opportunity take advantage of the long time series to do some comparative analysis for the same species and parameters across the ecosystem or basin as well as between species. There appears to be a need for more focus on the complete ecosystem structure and function to complement the strong bottom-up emphasis. An ecosystem modeler would be important to this work. Ideally having an operational ecosystem model could help integrate and interpret the suite of indicators presented in the California Current Ecosystem Report.

- **Theme 4 – Incorporation into Management**
  - Observations: The California Current Integrated Ecosystem Assessment (IEA) is a flagship of the national IEA program. It serves to communicate ecosystem science and climate information to managers and stakeholders, including the public. It recently was the focus of a positive review with recommendations for improvements. It appears to serve as an important mechanism to coordinate and integrate aspects of the Center's ecosystem research and a communication tool for the Western Regional Climate Action Plan.
  - Recommendations to address issue:

- **Theme 5 – Communication and Peer Review**
  - Observations The State of the California Current Report, produced annually to update a suite of physical and biological time series is an excellent product to communicate an ecosystem perspective and feeds into a more concise product for the Council that serves as an ecosystem considerations chapter, thus fulfilling and important Council need. The peer-reviewed publication record was quite variable with some staff

regularly publishing while others had long time series that colleagues in the same field outside the Center were not aware even existed.
    - Recommendations to address issue: Continue the State of the CC Report. Perhaps have a communications person produce a 1-2-page synthesis for the public. Review survey and field programs to identify where data analysis and publications are overdue and identify key publications to be produced.
- **Other: Climate**
    - Observations Both the Region and Council expressed a need to incorporate climate information in their actions. The Center has two major initiatives to address climate impacts. One is the Western Regional Action Plan (WRAP) and the other is the species climate change vulnerabilities work. A draft of the WRAP has been completed and is undergoing external review. This is a joint effort with the NWFSC and follows the approach presented in the NOAA Fisheries Climate Science Strategy. The WRAP does an excellent job of articulating the need to address climate change impacts in the management of the CC ecosystem and presents a broad and comprehensive approach to achieving that. It was developed by the West Coast Climate Committee to insure regional input. It leverages efforts of the CCIEA. It addresses building on the impressive historical and ongoing surveys including CalCOFI survey data and all the long term and ongoing survey data at the Center to build a strong monitoring base to detect climate change impacts. It identifies the use of output from earth system models in fishery and ecosystem models to project future ecosystem and fisheries impacts. Hake, sablefish, and North Pacific albacore were identified as three species that will be the focus of management strategy evaluations to assess climate impacts on stock assessments and management. An important component of the WRAP and the second major climate activity of the Center is the species vulnerability to climate change study. This will involve using output from climate and earth system models to project future climate impacts together with an expert working group to evaluate the sensitivity of 62 coastal species to the projected climate changes. A report is planned for completion by Sept 2016. This work is part of a national effort to conduct these studies for each region.
    - Recommendations to address issue: The Center's WRAP reflects a coordinated effort across the region and presents a comprehensive approach to climate work in the region and a valuable tool for Center research planning. The species vulnerability to climate change will be an important contribution to this work. Overall the Center is on track to address to support climate-informed management.